Functional Modelling, Scenario Development, and Options Analysis to Support Optimized Crewing for Damage Control

Phase 1: Functional Modelling

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DEPARTMENT OF NATIONAL DEFENCE

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ABSTRACT

The Canadian Navy hopes to achieve significant lifetime cost reductions by implementing optimized crew levels across its next-generation fleet. Defence Research and Development Canada (**DRDC**) has recognized that optimized crewing can only be achieved through a thorough Human-Systems Integration (**HSI**) effort, and that this effort will require systems modelling techniques to help the Navy predict the effectiveness of technologies and work strategies that aim to reduce operator workload and improve mission success. This report describes the first phase of a project undertaken to provide DRDC with such a technique, and details the development of an Abstraction Hierarchy (**AH**) functional model of the domain of damage control. Two subsequent phases of analysis are planned: to develop damage control scenarios, and to identify emerging damage control technologies and the reduced crew levels required to support them. These will be used as inputs for a follow-on project to develop a simulation of human and automated work in the damage control domain. The AH model documented in this report is a strong basis for the subsequent phases of this project, and the follow-on simulation development effort.

EXECUTIVE SUMMARY

In response to its recent strategic planning activity, the Canadian Navy is currently planning for a significant restructuring of their forces. Over the lifetime of a class of ships, personnel costs are much larger than procurement costs; accordingly, the Navy is hoping to develop a next-generation fleet that includes optimized crewing levels to reduce personnel costs. Defence Research and Development Canada (**DRDC**) has recognized that the Navy's objectives can only be met through a through Human Systems Integration (**HSI**) effort, and that this effort will require systems modelling techniques that will help the Navy to predict the impact of various crewing level and technology combinations on operator workload and mission success.

DRDC has recently initiated a project to provide the Navy with a systems modelling methodology that provides a workload simulation facility based on a functional model of the system of the interest. It is hoped that this methodology will allow for comparisons of the workload induced by various combinations of technology and crewing. Further, since it is expected that in the future crewing levels will be predicated on the crew requirements for damage control, damage control has been selected as the domain for the development of this new analysis suite.

This report describes the results of the first phase of this project, in which a functional model of the work system of damage control was developed. The particular form of functional model that was developed is called an Abstraction Hierarchy (**AH**), which is a framework for a particular type of Cognitive Work Analysis called Work Domain Analysis (**WDA**). Included in this report are the results of literature reviews carried out on the topics of optimized crewing and damage control, as well as the details of the damage control AH.

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SECTION ONE – INTRODUCTION

1.1 GENERAL

In response to its recent strategic planning activity (Canadian Department of National Defence, 2001), the Canadian Navy is currently in the early stages of planning for a significant restructuring of their forces (Canadian Department of National Defence, 2005). As the Navy's current fleet is retired, plans are underway to replace it with a next generation fleet. This fleet will be designed to meet two objectives. First, the Canadian Navy requires increased flexibility to allow it to respond to a broader range of threats and support missions that are expected to evolve over time. Second, the Navy also requires a fleet that will be more cost effective than the current fleet, and hopes to achieve this through reduced manning and commonality of equipment and training. Even though this new fleet is not expected to be operational until the mid 2020's, the long lead times involved in naval procurement (on the order of 10 to 15 years for the design and acquisition of a new warship) require that planning must begin now.

Defence Research and Development Canada – Toronto (**DRDC-T**) has recognized the important role that human performance will play in the accomplishment of the above objectives. To meet its objectives of expanding capabilities while reducing crew size, the Navy must find a way to amplify the capabilities of their crews. This will be achieved, in part, by equipping the fleet with new and advanced forms of automation that will permit the crew to better understand evolving situations and react promptly with optimal solutions. However, automation is not a panacea, and poorly conceived automation has the potential to actually increase operator workload (Bost, Mellis, and Dent, 1999) and make the joint human-automation system more susceptible to failures (Woods, 1996). Notwithstanding these 'ironies of automation' (Bainbridge, 1983; Wiener, 1989), automated systems have tremendous potential for success if their design and selection is based on a thorough human factors engineering (**HFE**) analysis.

In response to the Navy's strategic plan and their expected increase in reliance on automated systems, DRDC-T is seeking to develop expertise in both the selection of automation technology and the evaluation of human-machine systems that leverage automation. In terms of selection, they are seeking to develop systems modelling techniques that will help to generate guidance criteria for the selection of appropriate automation. In terms of evaluation, they are seeking to develop methods of workload modelling and analysis that can leverage the previous systems modelling effort and still provide valid and reliable results as to the impact of different crewing and automation options on human workload.

DRDC-T has identified the domain of damage control on board the Halifax-Class Coastal Patrol Frigate (**CPF**) as useful for the development of their expertise in these areas. While the damage control systems on the CPF are not scheduled for a major upgrade, DRDC-T expects that any insights gained from an analysis of damage control on the CPF will readily generalize to the proposed successor to the CPF, the Single-Class Surface Combatant (**SCSC**). Thus the domain of damage control on the CPF will provide useful insights both to address current concerns with respect to methodology development, and also to provide a sound basis for future analyses in support of the design and development of the SCSC.

1.2 PROJECT OBJECTIVES

The main objective of this project is to support DRDC-T in the development of an Integrated Performance Modelling Environment (**IPME**) simulation that will enable them to to assess the performance and effectiveness of a given level of crewing and automation by evaluating the impact of varying levels of crew and automation on damage control operations. The purpose of this project is not to develop the IPME simulation itself, but rather to perform three phases of analysis to serve that work:

a. **Phase I: Development of a functional model of damage control.** The first phase of this work is intended to develop a means-ends functional model of damage control that is not based on specific scenarios, crewing levels, or automation technologies. Rather, this model will reflect the full extent of CPF damage control functions in a manner that will afford later 'what-if' analyses to be conducted based on different scenarios, crewing levels, and automation technologies.

b. **Phase II: Development of damage control scenarios.** The functional model developed in Phase I will describe the 'landscape' of damage control on the CPF. The objective of Phase II is to develop two scenarios that describe medium and high-complexity trajectories across that landscape, respectively. As these scenarios will be used to test different crewing and automation options, it is important that they describe work that would unfold differently under different levels of each factor. Task inventories will also be developed for each of the scenarios that describe the atomic elements of work that could be assigned to either a human actor or to automation. Finally, measures of performance will be developed that allow for comparison of different combinations of crew and automation in the network. The work in this phase will form the foundational inputs to the eventual IPME model that is the end-goal of the larger project. The deliverables from this phase will be structured for portability to the IPME tool.

c. **Phase III: Specification of crew-automation options.** In this final phase, the work of the first two phases will be supplemented by the identification of possibilities for the automation of damage control, the specification of three options for damage control automation (the status quo option that characterizes the automation currently in use on the CPF; an intermediate option that uses currently available and tested automation technologies, and a full option that employs the full extent of the state-of-the-art in automation technologies), and the definition of the crewing levels required under the three automation approaches. As with Phase II, because this phase will produce inputs to the final IPME model, it is important that the crew-automation options be specified in ways that are readily portable to IPME.

To ensure that results of all three phases accurately represent the reality of damage control operations on the CPF, it is important that all work be performed in close consultation with relevant Subject Matter Experts (**SMEs**). This will ensure that the functional model, damage control scenarios, and crew-automation options accurately capture the subtleties of the damage control domain, and ultimately, that the final IPME model will be valid and reliable.

1.3 RATIONALE – THE ABSTRACTION HIERARCHY

The functional modelling work carried out to fulfill the first phase of this project is based on a specific type of functional, means-end model, called the Abstraction Hierarchy (**AH**), which is a framework for Work Domain Analysis (**WDA**). The AH and WDA have a long history (e.g., Rasmussen, 1985; Rasmussen, Pejtersen, & Goodstein, 1994; Vicente, 1999; Burns & Hajdukiewicz, 2004; Naikar, Hopcroft, & Moylan, 2005) and have been adopted by industry (e.g., Jamieson & Vicente, 2001; Vicente, 1999; Burns & Hajdukiewicz, 2004) and military organizations (e.g., Bisantz, Roth, Brickman, Gosbee, Hettinger, & McKinney, 2003; Burns, Bryant, & Chalmers, 2005; Naikar & Sanderson, 2001; Naikar, Pearce, Drumm, & Sanderson, 2003; Naikar, Hopcroft, & Moylan, 2005) around the world. The AH and WDA are well-suited to this project for the following reasons:

a. **AH models are actor-independent.** AH models describe the functional possibilities and constraints of a work domain independent of the human or computer agents chosen to operate on that domain. As actor-independent models, the AH allows for crewing and automation options to be superimposed on the AH in later stages of analysis. This feature of the AH makes it particularly relevant for this project, as an AH is a good foundation for the comparison of multiple different crewing-automation options.

b. **The AH and WDA are uniquely suited to complex systems.** The domain of damage control has all of the hallmarks of a complex socio-technical system (Vicente, 1999). Most significantly, damage control has a large problem space that involves significant hazard, involves a great deal of uncertainty, is prone to disturbances, and has many complex interactions (for example, water pumped into one compartment affects the mass balance of the entire ship; the contents of a compartment can cause a fire to spread unpredictably; sealing off a compartment could compromise functions critical to other parts of the ship). The AH and WDA were explicitly developed for the analysis of these types of systems, and provide a language that helps to make the many interacting levels of work in these systems understandable and relevant to follow-on HF analyses.

c. **The AH and WDA are uniquely suited to domains that are susceptible to unanticipated faults.** Although Damage Control officers (**DCOs**) tend to train for a set of stereotypical damage control scenarios, real damage control situations are often unique and have one or more fault types that could not be anticipated by systems designers. AH representations are particularly robust for this sort of domain because they go deeper than operators' strategies for solving particular problems to represent the constraints under which a system operates. An AH model should help in determining more comprehensive requirements for automated solutions than a traditional task analysis.

d. **The AH and WDA help to generate more comprehensive scenarios.** An important output of the proposed work will be a set of scenarios from which a set of IPME simulations can be built. An AH is a good foundation for developing these scenarios because it maps out the functional landscape of the domain so that scenarios can be developed that exercise a representative slice of the domain complexity. As an example, Schraagen (1996) found that expert DCOs used functional relationships between ship spaces to develop predictions of the consequences of calamities. In contrast, novices tended to consider only the physical proximity of spaces and the type of adverse event in predicting outcomes. Using the WDA, it will be possible to design scenarios that combine calamities that are physically and functionally related or unrelated.

e. **The AH and WDA help to identify possibilities for automation.** In addition to representing the constraints of a work domain, an AH also represents the action possibilities, or affordances (Gibson, 1979; Torenvliet, 2003) available in a work domain. These affordances identify the atomic units of work that will, depending of the crewing-automation options that are developed, be assigned to crew members or automation (Bisantz, *et al.*, 2003). This will both help to speed the development of the various crew-automation options as well as ensuring that the definition of these options is rigorous enough to support an IPME analysis.

In sum, the AH and WDA are a strong foundation for the development of an IPME simulation to analyse the workload effects of different crew-automation options on the domain of damage control. The AH model will help in the identification of the functional possibilities that can be exploited by either operators or automation, in the creation of scenarios that properly exercise the work domain, and in the selection of automation that will have a high likelihood of minimizing crew size requirements while still promoting safe and effective work. In addition, an AH model helps to capture the domain in a way that supports the comparison of different crew-automation models, and provides outputs that are readily portable to IPME.

1.4 PURPOSE OF THIS REPORT

This report provides a summary of the work completed for the first phase of the larger project described in Section 1.2, above.

1.5 REPORT OUTLINE

This Concept report consists of the following sections:

a. Section One – Introduction

b. Section Two – Methodology

c. Section Three – Results

d. Section Four – Conclusions and Recommendations

e. Section Five – References

f. Annex A – Glossary of Terms and Acronyms

g. Annex B – AH Questionnaire

h. Annex C – Notes from SME Interviews

i. Annex D – Bibliography of CPF Documentation

1.6 ACKNOWLEDGMENTS

The authors would like to acknowledge the extensive and cheerful assistance that was given by members of the Canadian Forces to this project. Lieutenant Commander (**LCdr**) Roger Heimpel deserves special thanks for his assistance during a four day visit of the project team to the Canadian Forces Naval Engineering School (**CFNES**). LCdr Jacques Olivier was also extremely helpful in the conduct of this work, has answered many of our questions quickly and succinctly, and has participated in a number of interviews and review sessions. LCdr Jeff Hardy was also found able to participate in a review session on very quick notice, and was able to ensure that the model received a thorough review from the point of view of Combat Systems Engineering (**CSE**). LCdrs Nigel Kennedy and Bruce Grychowski, Commanders (**Cdrs**) Jean Lavallée and André Gagnon, and Chief Petty Officer (**CPO**(**CPO**)) Kenneth Pretty were also helpful in volunteering to be interviewed for their perspectives on damage control on the CPF. Many others helped us find materials or pointed us in the right direction for securing resources. We are grateful for this assistance; this phase of the project could not have been completed without it.

SECTION TWO – METHODOLOGY

2.1 GENERAL

This section details the methodology used to produce the AH model for damage control.

2.2 DOMAIN ANALYSIS

2.2.1 Overview

The first step in building an AH model of a work domain is to gather information about the domain to support the model building effort. There are typically three different sources of information about the domain – information in the academic or trade literature about the domain in general, information in engineering documentation from the system to be analysed about the specific domain as designed, and information in operators' heads about the specific domain in practice. The project team carried out review and interview activities to gather each of these three types of information, as documented below. In addition, because the driver for the overall project is the specific concern of optimized crewing, a brief review of the literature on optimized crewing was also performed.

2.2.2 Review of the Optimized Crewing Literature

Since the outputs of this overall project will be the production of a method to assess the performance and effectiveness of a given level of crewing and automation to validate crewing configurations in the service of optimized crewing efforts, the first step of the domain analysis was to perform a brief review of the optimized crewing literature. The starting point for this review was a DRDC report on crewing reduction (Beevis, Vallerand, and Greenley (2001)), an American report to congress reviewing recent efforts in crewing reductions (United States General Accounting Office, 2003), and a RAND Europe report discussing efforts towards optimized crewing on the UK's current Future Aircraft Carrier program (Schank, Yardley, Riposo, Thie, Keating, Arena, Pung, Birkler, and Chiesa, 2005). A brief review was also conducted of the materials available via the www.manningaffordability.com website, the homepage of the now defunct SC-21/ONR S&T Manning Affordability Initiative.

2.2.3 Review of the Damage Control Literature

In addition to reviewing the literature on optimized crewing in general, the literature on damage control was also reviewed. This starting point for this review were two DRDC reports (Hiltz, 2005a, 2005b), and also included a summary report of the US DC-ARM damage control system (Runnerstrom, 2003), and one paper detailing an academic study of damage control (Schraagen, 1996).

2.2.4 Review of CPF Documentation

While the first two literature review efforts were designed to inform the project team about damage control concerns in general, an additional review phase was performed to gain familiarity with the CPF. For this effort, the project team was provided with a CD-ROM of Canadian Forces Damage Control and Sea Training Manuals, and also gained access to a copy of the CPF Ship Standing Orders (**SSOs**) and the CSE Emergency Response Team (**ERT**) documentation. Since the volume of literature available for the CPF is large, the review could not be exhaustive. Instead, it was intended to provide the project team with a good familiarity with the CPF and its damage control operations to facilitate discussions with SMEs.

2.2.5 Interviews with Subject Matter Experts

While reviews of the literature provide an important perspective on damage control, interviews with experienced operators are necessary to understand the practice of damage control in depth. The project team was fortunate to be able to spend a significant amount of time with damage control SMEs, and performed the following interviews:

a. **Introductory interviews – January 18 and 25, 2006.** Early in the project, six CF personnel volunteered to be interviewed so that members of the project team could learn about damage control in general as well as these operators' personal experiences. Mr. Torenvliet and Mr. Cournoyer were able to spend an afternoon with LCdrs Jacques Olivier and Nigel Kennedy learning about the Maritime Systems Engineering (**MSE**) perspective on damage control. Later, Mr. Torenvliet was able to conduct interviews with Cdrs Jean Lavallée and André Gagnon learning about the command perspective on damage control, with LCdr Bruce Grychowski learning about the CSE perspective on damage control, and finally with CPO Kenneth Pretty learning a more operational perspective.

b. **Deepening interview – January 30, 2006.** Mr. Torenvliet was also able to spend a full day interviewing LCdr Roger Heimpel, the Commanding Officer (**CO**) of the Damage Control Division of the CFNES in Halifax. The first portion of the day was used to get a training perspective on damage control, and the focus was very strongly on the ways in which damage can occur on a ship and the ways in which it can be controlled. This interview also included observations of training exercises in progress at the school, with explanatory commentary from LCdr Heimpel. After the interview, LCdr Heimpel gave Mr. Torenvliet a tour of the HMCS Montreal that was docked in Halifax. During the tour, LCdr Heimpel highlighted all of damage control systems across the ship to help put the morning's interviews into context.

c. **AH interview – January 31, 2006.** On January 31, 2006, the full project team joined Mr. Torenvliet and LCdr Heimpel to conduct a day long focused AH interview session. During this interview, the AH questionnaire developed by Naikar, et al. (2005) was used to engage LCdr Heimpel in focused conversations about the various possible levels that could be included in the AH and the contents of those levels. (This questionnaire is included as Annex B)

In general, these interviews were conducted informally. Although the project team hoped to be able to make use of the Critical Decision Method (**CDM**; Flanagan, 1954; Crandall & Getchell-Reiter, 1993; Hoffman, Crandall, & Shadbolt, 1998) in these interviews, during their conduct it quickly became apparent that the team did not have the required background domain knowledge to make proper use of this technique; each critical incident rapidly turned into another object lesson in damage control, rather than a true critical incident interview. Even though the

CDM did not prove useful in this context, the interviews were still useful, and the project team collected their observations in notes and in a set of audio recordings.

Transcripts of the notes from the interviews on January 18 and 25, 2006 are attached as Annex C.

2.3 MODEL CONSTRUCTION

After the domain analysis was complete, the project team began the work to construct the AH for damage control. While the actual process of construction was iterative, the steps that were followed were roughly as follows:

a. **Establish the objective of the analysis.** The first task was to briefly review the motivation for the model building exercise and to state its objectives. Once formulated, these objectives were used to guide decisions on the modelling scope and depth.

b. **Define the system boundary.** The next task was to define the system boundary. As can be seen in the results presented in Section 3.3.3, this was a challenge because it was first necessary to resolve the fact that damage control is not a work domain, but is an object world in the more general work domain of ship's system (see Section 3.3.3 for an explanation of object worlds). Once this issue had been resolved, the task of defining the system boundary was straightforward.

c. **Identify and arrange the levels of abstraction that are meaningful to SMEs.** After defining the system boundary, the project team then revisited the results of the interviews that had been conducted to determine the levels of abstraction that were used by SMEs in their descriptions. It was confirmed that the standard levels of abstraction (Functional purpose, Abstract function, Generalized function, Physical Function, and Physical form) are indeed relevant to damage control on board the CPF. This provided the overall structure for the detailed model construction that was to follow.

d. **Populate the levels of the hierarchy with ship compartments, damage control functions, high- and low-level functions, and purposes.** With the foundational modelling decisions in place, the project team began to flesh out the AH model. In this analysis, the functional purposes were quite clear from the interviews with SMEs, but it was not immediately obvious how the functional purposes would work down to the affordances for damage and damage control in each of the compartments on the ship. A number of different models were constructed before the importance of the fact that damage control is an object world, but not actually the work domain itself, was understood. Once this insight fell into place, the levels of the model were populated relatively quickly.

e. **Determine the structural means-ends connections between adjacent levels of the hierarchy.** Damage control involves a great deal of problem solving from the low-levels of abstraction that describe the compartments on the ship to the high-levels of abstraction that help operators to prioritize damage control efforts across multiple instances of damage. For this reason, the structural means-ends links were a key part of the analysis, and they were considered and filled in at the same time as the nodes of the AH at each level.

f. **Determine the causal connections between nodes in the same level of the hierarchy.** Problem solving in damage control involves consideration of highly coupled and interlinked issues. For instance, pumping water on a fire can serve to put the fire out but will also reduce the reserve buoyancy of the ship. To represent the importance of these causal links, the last high-level modelling effort was to determine the causal links at each level of the AH so that the tradeoffs inherent in damage control could be captured.

2.4 MODEL REVIEWS

After its initial development, the AH model of damage control was refined through three separate reviews:

a. **Review of initial model with LCdr Heimpel.** The initial AH model was reviewed with LCdr Heimpel while the project team was still at the CFNES in Halifax. The initial model was presented to LCdr Heimpel and the discussion progressed through each node and each structural means-ends link. A number of important refinements were made, but the project team felt confident after this review that the model was substantially correct, if not yet detailed enough.

b. **Scientific Authority (SA) review of an interim model.** Dr. Chow was able to review the model on 22 February 2006. By this time, the model had been filled out with additional details, and while Dr. Chow requested a number of changes at the detail level, again the structure of the model held.

c. **Formal review of the draft final model.** By March 20, the project team was of the opinion that the model was complete enough for a final and formal review by a team of SMEs. LCdr Jacques Olivier and LCdr Jeff Hardy participated in the review and represented the concerns of MSE and CSE respectively; Mr. Curtis Coates (an ex-MARS officer with executive officer experience) also participated as necessary to represent command and control concerns. The thorough review of these SMEs was productive, and uncovered a number of important items in the model that needed rework. Still, the changes were small enough that they could be fully worked out and accepted during the meeting; consequently, at the close of this review, the project team was content that the AH model was complete.

2.5 MODEL DOCUMENTATION

After the final review of the model, detailed documentation was produced to represent each node and link in the model; this documentation can be found in Section 3.3.6. A number of low-level changes were made to the model in the process of documentation, to result in the model that is presented in this document.

SECTION THREE – RESULTS

3.1 GENERAL

This section presents the two major results for Phase I of this project – the reviews of the literature on optimized crewing, damage control, and CPF documentation, and the AH model of damage control.

3.2 LITERATURE REVIEW

3.2.1 Overview

This section presents the results of the reviews of the literature that were carried out to familiarize the project team with the topic of optimized crewing, the domain of damage control, and the CPF itself. Due to time constraints, the results have not been summarized into a single thematic-style literature review; instead, the contribution of each of the sources consulted to the current project is briefly summarized.

3.2.2 Review of the Optimized Crewing Literature

3.2.2.1 Beevis, Vallerand, and Greenley (2001). <u>Technologies for workload and crewing reduction: Phase I project report</u> (Defence R&D Canada Technical Report DCIEM TR 2001-109).

This report details an in-depth study conducted by DRDC-T to identify known crew reduction technologies for the Navy and to classify them based on the cost of implementation – from no cost to the major cost of a ship refit. This study was very broad, and technologies were identified for crew reduction for the full set of functions on the Iroquois and Halifax classes of ships.

It is notable that many of the technologies identified in this report relate to damage control either indirectly (e.g., centralized machinery monitoring and control systems, redundant ship systems) or directly (e.g., centralized damage control information systems, automatic fire detection and suppression systems, damage control automation). More significantly, this report identified that there was currently no way to assess current workload on ships, or the potential of new systems to reduce workload.

3.2.2.2 United States General Accounting Office (2003). <u>Navy actions needed to optimize ship crew size and reduce total ownership costs</u> (Report GAO-03-520).

This report was produced by the US General Accounting Office (**GAO**) in response to a request from the US congress for the GAO to investigate the US Navy's progress in optimizing the crew size in four different programs: the DD(X) destroyer, the T-AKE cargo ship, the JCC(X) command ship, and the LHA(R) amphibious assault ship. The most notable finding of this report is that crew optimization can only be achieved if specific crew size reduction goals are set early in the program, and that the crew reduction effort is implemented with an early and thorough Human Systems Integration (**HSI**) program. The report is also helpful in pointing out the most important roadblocks to crew reduction, including funding constraints on the early activities of design, development, and acquisition (these constraints actually increase the total cost of ownership of a class of ships), and the long-standing traditions of the Navy that resist deviation from time-tested ways of working. The report suggests that best way to ensure that crew optimization efforts are embarked on and have measurable success in reducing the total cost of ownership of a class of ships is through high-level policies that mandate the use of HSI in procurement.

The appendices of this report, especially Appendix IV, are also useful in the context of the current project. This appendix summarizes the crew reduction efforts for the DD(X) class of destroyers and demonstrates how crew reduction efforts must take all tasks in the ship, from the types of paint used on the ship through laundry and food service to damage control and bridge watchstanding.

3.2.2.3 Schank, J., Yardley, R., Riposo, J., Thie, H., Keating, E., Arena, M., Pung, H., Birkler, J., and Chiesa, J. (2005). Options for Reducing Costs in the United Kingdom's Future Aircraft Carrier (CVF) Programme. Santa Monica, CA: RAND Corporation.

The Royal Navy (UK) has recently commenced the Future Aircraft Carrier (**CVF**) programme in order to acquire two new ships to replace their current Invincible-class carriers. This is an ambitious project that, if successful, will equip the Royal Navy with the largest and most powerful warships it has ever had: these new carriers will be over three-times the size of the ships they are replacing (65,000 vs. 20,000 tonnes displacement).

Since the expected service life of these new ships will be quite lengthy (50 years), and since lifetime costs of the project will be large (on the order of £ 4.5 B), the Royal Navy is investigating ways to balance the acquisition and support costs of this ship to optimize the overall, or whole-life cost (**WLC**). As a part of this effort, they asked the RAND Corporation to devise a model for projecting the WLC of the CVF, to recommend ways to reduce those costs, and to investigate the ways in which other naval programs across the world have tackled with the same issues.

Although the CVF is a ship on a scale well beyond both the CPF and the proposed SCSC, this report is nonetheless a valuable introduction to the many issues involved in reducing the WLC of a ship. It is especially valuable because of its breadth – the authors' mandate was not simply to investigate technology for reduced workload and crewing (cf. Beevis, Vallerand, and Greenley, 2001), but more broadly to reduce the overall operating costs of the ship. The authors consider options from providing soft drinks from restaurant-style fountain dispensers instead of in cans (because this will save on waste storage and disposal costs) to full-automation of critical system functions including damage control. In the process, they provide a model that helps the reader to gain sensitivity for the many issues involved in reducing the overall crewing cost.

The authors have also completed a thorough analysis of the effect of the size of the CVF crew complement on operating costs. This discussion includes begins with a review of the size of crew complements over the past century (from 105 crewmembers per 2,000 tons from 1916-1977 to 47 or fewer crewmembers per 2,000 tons since 1995). Of special relevance to this current work, the authors also include a discussion of the various tradeoffs involved in reducing the crew complement. First of all, they highlight that since each crewmember performs many different ship functions, workload reduction efforts need to target a wide variety of ship functions in order reduce the crew complement. Second, they mention the difficult compromise that must be struck between having the work performed by the least-expensive capable crew while still retaining an appropriate number of specialists on-board. The discussion on crew complement size is rounded out by a set of complement-reducing principles that the authors propose might be useful for the CVF programme. Notably, their first recommendation is that crew complement reduction efforts should be guided by the ‘manpower drivers’ of a ship’s work, and further that damage control functions are one of the most important manpower drivers on a carrier.

Chapter 7 of this report, titled “Complement-Reducing Initiatives on Other Platforms”, is worth an in-depth read. In this chapter, the authors present case-studies of optimized crewing efforts that have been performed on other naval programs: the US Military Sealift Command, the US CVN carrier programme, the US Smart Ship programme, the Optimized Manning Experiment, the DD(X) programme, the US Navy’s new LPD-17 class, and practices in the Royal Netherlands Navy. This chapter demonstrates the breadth of concerns involved in crew-reduction efforts, but also focuses on efforts to reduce the manpower required for damage control. Notably:

a. Current US ‘Smart Carriers’ include an advanced damage control system that leverages a ship-wide Local Area Network (**LAN**) to distribute damage control information across the ship, including information about from sensors, damage control consoles, and closed-circuit television signals. This is expected to evolve into an automated damage control system in near-future carrier projects.

b. The US Navy’s ‘Smart Ship’ programme also employed a LAN but this time in conjunction with Commercial-Off-the-Shelf (**COTS**) products to reduce workload for both CSEs and DCOs.

c. The US Navy’s LPD-17 amphibious ship program includes a ‘real time’ damage control system that has allowed them to do away with grease-pencil damage recording on laminated damage control plates.

d. The Royal Netherlands Navy is a world-leader in employing both technology and policy to reduce crewing on their ships. Newer ships have been equipped with advanced built-in systems for first response to damage situations so that personnel are not required on the bridge at all times and can instead be used to perform other duties such as cooking and cleaning. In addition, the Dutch are at the forefront of automation research, as was evidenced by a collection of references from the 2002 Ship Control Systems Symposium to Dutch research on advanced automation.

e. The US Navy’s DD(X) programme will include highly advanced technology, including an autonomic fire suppression system and integrated power system, which will help in achieving a crew complement of 125.

The last chapters of this report bring the focus back to the CVF programme by proposing a set of interventions that could foster a reduced crew and evaluating them. Specific to damage control, they provide a good summary of the crew-reduction options already presented earlier in their report. It is also notable that the damage control options are presented first in their list; clearly reducing the workload of damage control is a key lever to achieving reduced-crewing objectives. The authors also present a useful evaluation framework that categorizes each crew-reduction option by operational risk and level of technical readiness.

In summary, this report presents a thorough review of the state-of-the-art in reduced crewing options. It provides much useful context for this project, and also includes pointers to information that will be valuable especially for the work of Phase III.

3.2.2.4 Bost, J. R., Mellis, J. G., & Dent, P. A. (1999). Is the Navy serious about reducing manning on its ships?

This paper is a summative analysis of US Navy efforts at crew reduction. It opens with the observation that despite 40 years of effort in crew reduction, complements on today's ships are virtually at the same levels as in the 1960's. The authors contend that very little progress has been observed because the US Naval culture is resistant to the types of changes and decisions that need to be made in order to achieve reduced crewing levels. Even though automated systems (and even 'autonomic ships') show great promise for reducing crew levels, the Navy is generally sceptical about automation and holds to a large list of misconceptions about the risks and consequences of such systems. Of interest to this current work, the authors of this report do concede that while automated systems can reduce crewing levels in general, crew reductions could compromise a ship's damage control capability.

The authors also present a set of broader cultural and organizational issues that stand in the way of optimized crewing efforts. Most importantly, the authors concur with the US GAO report cited earlier (GAO, 2003) and believe that the current regime in which "acquisition costs take precedence over life cycle costs" militates against reduced crewing efforts. The authors' overall conclusion is that significant cultural and organizational factors must be overcome if the Navy is to implement any form of optimized crewing.

3.2.2.5 Hamburger, P. S., Bost, J. R., & McKneely, J. A. (1999). Optimized crewing for surface ships. Naval Surface Warfare Technical Digest, 204-215.

This report presents an overview of the work necessary to achieve an optimized crewing strategy for a surface ship. It begins with a very helpful definition of optimized crewing: "It is the minimum crew size consistent with risk, affordability, human performance capability, and workload" (p. 204). Noteworthy as well is the story-based operational vision of how a ship with optimized crew would detect, track, and respond to a missile attack from an unknown contact. The remainder of the report discusses the process to achieve an optimized crew, and touches on issues such as human performance, workload, safety, reliability, and quality of life at sea. It closes with a review of a number of research initiatives that show promise for enabling optimized crewing.

3.2.3 Review of the Damage Control Literature

3.2.3.1 Hiltz, J. A. (2005a). Damage control and crew optimization. DRDC-Atlantic Technical Memorandum TM 2005-010 *and* Hiltz, J. A. (2005b). Damage control and optimized manning: The DRDC-Atlantic perspective. DRDC-Atlantic SL 2005-149.

These two reports describe the initiation of a research program at DRDC-Atlantic to investigate means toward achieving optimized manning for damage control: Hiltz (2005a) seems to be an initial memorandum about the program, while Hiltz (2005b) is a higher-level description that also includes details of the program that were decided in the six months between the 2005a and 2005b reports.

The introductory portions of these reports provide a thorough rationale for performing focused research into the possibilities of optimized crewing for damage control. Traditionally, damage control has benefited from large crewing requirements in other portions of the ship. However, as those crewing requirements are reduced by the introduction of new technology, damage control will soon become the limiting factor in crew optimization efforts. Damage control remains a labour-intensive task, and even if fire suppression can be automated, flood control seems relatively impervious to technological developments – it remains difficult to automate front-line repairs to breaches in a ship's hull.

Having established the need for research into optimized crewing for damage control, Hiltz then outlines a broad program of research to this end. This program has seven separate work elements:

a. **Remote condition monitoring systems.** This work element will investigate the development of Condition-Based Maintenance (**CBM**) sensor technologies for use on Canadian ships. These sensors will be able to detect and monitor the condition of ship's systems, so that maintenance can be performed when needed, instead of on some idealized schedule. CBM technologies should increase the mean time between maintenance activities, and so should lower the crewing requirements for maintenance. CBM technologies also have a spin-off benefit to damage control, as it will become easier to detect and diagnose equipment damage across the ship.

b. **Modelling and simulation of ship complements.** This work element will investigate the opportunities for using modelling and simulation technologies to investigate the workload effects induced by various combinations of damage control automation and crew levels.

c. **Fire control / sensing and suppression.** This work element will investigate technologies for fire sensing and suppression, to the end that fires can be sensed and responded to quickly and reliably. This research also aims to find suitable replacements for some of the fire suppression agents currently used on Canadian ships that have negative environmental impacts, as well as technologies for remote ventilation and access control.

d. **Damage control.** This work element will investigate advanced sensor technologies for aspects of damage control beyond fire and smoke, as well as advanced damage control systems. This will include technologies for automatic reconfiguration of fire mains and remote closing of doors and hatches.

e. **Remote Condition Monitoring Systems**. This work element is similar to work elements (a), (d), and (e) and will investigate CBM-like approaches to monitoring the overall condition of ship with respect to damage control, including structural damage, flooding, and fire main pressure.

f. **Enhanced materials**. The objective of this work element is to investigate the development and application of materials that have enhanced damage tolerance or reliability. If successful, these materials will help to mitigate the effects of battle damage.

g. **Human factors.** This work element will consider how best to present information from the new technologies being considered to human operators, as well as the training requirements for use of the new systems.

Since the work described in this present report has been completed towards the second work element (Modelling and simulation) described by Hiltz, the broader research program described by Hiltz is an important consideration for this work. It will be important to keep abreast of the developments in especially work items c-f, as those findings could be beneficial to Phase III of this project.

3.2.3.2 Runnerstrom, E. (2003). Human systems integration and shipboard damage control. Naval Engineers Journal, 115, 71-79.

In this paper, the author makes an argument for the application of HSI to the development of naval systems in general and damage control systems in particular. The overall structure of the paper motivates the need for HSI by describing the poor state of current ship capabilities for dealing with abnormal situations, proposes HSI as a promising way to help improve ship capabilities while reducing crew levels, presents the Damage Control Automation for Reduced Manning (**DC-ARM**) system developed by the US Navy as one example of effective HSI, and concludes with remarks about the obstacles to implementing HSI in US naval programs.

Runnerstrom's motivating arguments are quite convincing. He recounts studies in which it took experienced damage control teams at least 20 minutes to isolate representative damage to a firemain. During this time, the firemain was unavailable for fighting fires, and a fire that was part of the same scenario spread dramatically.[1] Repairs to the firemain were slowed by poor coordination between the central damage control management and the team working to repair the firemain, so that the two teams were actually working at cross purposes. Runnerstrom prevents evidence from actual incidents to prove that a response time of 20 minutes for firemain isolation is not the exception, but the norm, and that poor HSI in the design of the damage control system is to blame for the system's poor performance: "Experience from tests … corroborates the firemain experience that ship systems have generally been designed with little effective consideration of the role of the human operators."

The author presents the DC-ARM system as an example of effective HSI. One of the aspects of this system was supervisory control for the firemains across a ship so that a central operator could maintain a good understanding of the configurations of the firemains across the ship and re-route them as necessary. The system also included fitted water-mist fire suppression and containment systems, better fire detection sensors, remote control of access closures, and a smoke ejection system. The system was designed based on an extensive functional modelling exercise that considered how best to assign functions to automation or to personnel, and that

[1] According to one of the SMEs interviewed for this current work, if a fire is not being contained or suppressed, it will double in size every 20 minutes.

provided the basis for display design. The benefits of this approach were many: effective HSI ensured that requirements were discovered early and synthesized sensibly so that the computer coding effort took approximately half what would be expected for a system of conventional size using traditional systems analysis techniques. More importantly, testing of the DC-ARM system on the *Ex-USS Shadwell* demonstrated improved damage control effectiveness along with a 60% reduction in crew.

Runnerstrom's review of the obstacles to an effective HSI program are similar to those covered in Bost, *et al.* (1999) and GAO (2003), but his analysis includes more depth based on his practical experience with the development of the DC-ARM system. One of the obstacles noted by Runnerstrom that is most relevant to this project is the lack of formalized HSI methods; it is hoped that the results of this current project will go part-way toward surmounting that obstacle.

3.2.3.3 Schraagen, J. M. C. (1996). Requirements for a damage control decision-support system: implications from expert-novice differences. In C. Zsambok & G. Klein (Eds.), Naturalistic Decision Making (pp. 227-232). Mahwah, NJ: Lawrence Erlbaum Associates

In this paper, Schraagen details work that he performed to understand the reasoning processes of DCOs, and then to design a decision-support system to help these operators in their task.

In an introductory section, Schraagen discusses the complexity of the damage control task, and how it is compounded by the fact that even experienced DCOs may have never actually experienced a damage control situation outside of training exercises. Thus it is unlikely that these operators have a repertoire of prototypical damage control situations to draw from, as other researchers found was the case for land-based fire-fighters.

Schraagen's hypothesis is that DCOs are able to function well not because they have a good understanding of damage, but rather because they have a good understanding of their ship and its damage control characteristics. Schraagen tested this hypothesis by asking novice and experienced DCOs to respond to various damage control scenarios using action generation and scenario recall. He found that experienced operators were able to more reliably generate actions and make predictions about how fires spread based on their knowledge of the potentially dangerous compartments to which damage could spread.

Based on these results, Schraagen designed a damage control decision support system to help operators understand (a) the ways in which fire can spread from compartment to compartment, and the consequences of that spread, and (b) the consequences of decisions to close firemain valves. While Schraagen does provide references to more detailed descriptions of this system, he unfortunately does not present any experimental evidence to demonstrate the efficacy of the new design.

3.2.4 Review of CPF Documentation

The reviews of the optimized crewing and damage control literatures helped us to gain familiarity with the work system of damage control, but more importantly, they helped us to understand how the current project fits into the overall research on damage control and optimized crewing. The review of the CPF documentation was different in this regard. Instead of helping us to understand the broader research context of this project, it formed an important part of the low-level data gathering for the model construction effort. Since this review provided a good deal of the data represented in the AH model, separate results of the review of the CPF documentation are not provided; the AH model should be sufficient for this purpose.

A list of the CPF documentation consulted has been attached as Annex D.

3.3 ABSTRACTION HIERARCHY

3.3.1 Overview

This section presents the AH of the work system of damage control. It begins by specifying the purpose of the current analysis and establishing a system boundary, continues with a discussion of some of the high-level characteristics of the model, and finally describes the AH that was produced at both high- and low-levels of detail.

3.3.2 Analysis Objective

The objective of the current analysis was to develop an AH model of damage control that will be the basis for the future activities described in Section1.2 of this report. With reference to each future phase of work, the purpose of the current AH analysis is as follows:

a. **Scenario development.** The AH must describe the system at a level that will afford the development of damage control scenarios, both in terms of describing the elements of the work domain that are relevant to damage control and in terms of providing a work domain map for evaluating how comprehensively a set of proposed scenarios covers the work domain.

b. **Options analysis.** The AH must describe the system in a way that affords the specification of three different crew-automation options for a damage control system – one using equipment and automation currently in use on the CPF, a second using equipment and automation currently available in the market but not yet in use on the CPF, and a third using the full extent of the state-of-the-art in automation technologies.

c. **Workload simulation and analysis.** Ideally, the AH must describe the system in a way that will bootstrap the development of a discrete-event simulation of the damage control work domain on the CPF that will allow for the evaluation of the performance and effectiveness of the various crew-automation options.

3.3.3 Stakeholders and Object worlds

As defined in WDA practice, a work domain is the set of physical and functional constraints on purposeful action in a work context. These constraints are event-independent (Vicente & Tanabe, 1993) and cannot be exhaustively identified though analysis of worker tasks in that context. Thus, the only proper foundation for a WDA is a work domain that is defined without reference to any tasks undertaken in it. In this ‘pure’ WDA sense, ‘damage control’ does not refer to a work domain. Though it is difficult to find a precise definition of damage control, references that either implicitly or explicitly define it always treat it as a set of tasks that occur either to prevent or respond to internally or externally induced damage. For example, the

Canadian Maritime Command's SSOs define damage control with respect to a set of damage control tasks, and Schraagen (1996) defines damage control as "a Command and Control task, consisting of a cycle of processes" (p. 227). In WDA terms, damage control is 'event dependent' whereas a work domain for WDA analysis must be 'event independent' (Vicente & Tanabe, 1993).

Since 'damage control' as typically construed is not a work domain, before defining the system boundaries (the typical first stage of a WDA), it was important to first discover the work domain of which damage control is a part. To do this, the project team made reference to WDA thought in the area of stakeholders and object worlds (see Naikar, et al. (2005) for a review). The idea is that different stakeholders may have different views of or into a work domain. For instance, in a study of network management, Chow and Vicente (2001) found that stakeholders outside and inside of the company with ownership of the network operated under different views of the same work domain. In such a case, each stakeholder has a different 'object world' within the same work domain.

Applied to the context of damage control, the concepts of stakeholders and object worlds help in viewing damage control as one of the object worlds within the CPF. Damage control operates within, and so is an object world of, the work domain of the ship systems. Other object worlds in the same domain include (but are not limited to) MSE, CSE, and Command and Control, as shown in Figure 3-1, below.

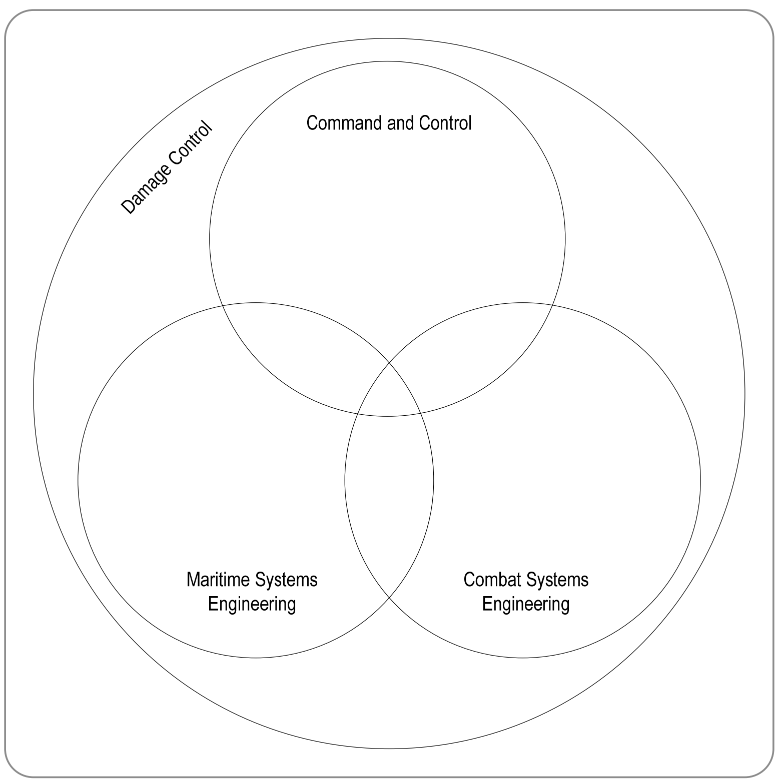

Figure 3-1. Object worlds within the ship systems work domain

Two things in this diagram are notable. First, damage control forms the largest object world within the work domain of the ship systems. This object world includes all ship spaces in terms of the damage they could sustain, as opposed to the object worlds of, for example, MSE and CSE that include only select ship subsystems.[2] Second, while the concerns of damage control are broad, they are also relatively shallow. Damage control's prime responsibility is to restore the ship to the state necessary for Command and Control, CSE, and MSE to meet their objectives; damage control is a facilitator.

3.3.4 System Boundary

Having established that damage control is an object world within the work domain of the ship systems, the next step was to define the boundary of the ship systems. As it turns out, the boundary for this analysis was simple and straightforward. It consists of the ship hull, deck, and superstructure and any objects on or attached to the same. Items external to the ship (e.g., weather, the sea, projectiles, etc.) are considered to be a part of the environment.

Since one of the objectives of the modelling effort is to afford the specification of three different crew-automation options, current ship subsystems for or related to damage control were excluded from the analysis. Most obviously, this included fire mains, fitted and portable fire-fighting equipment, and smoke and heat sensors. In addition, since the design of a power distribution network can have a large effect on the damage control work domain (for example, Schank, *et al.* (2005) report that the US Navy's new DD(X) program proposes to meet its reduced manning goals via an automated damage control system coupled with an integrated power system), the physical form of the power distribution network was also excluded from analysis.

In addition, Nuclear, Biological, and Chemical Defence (**NBCD**) has also been excluded from the analysis in the interest of controlling scope. NBCD concerns add important constraints to the work domain, but those constraints are layered on top of the normal (i.e., non-NBCD) constraints when an NBCD event arises. It was determined that NBCD would add too much complexity to the current analysis as well as to further project phases, and that the development of a method to support workload analysis in support of crew optimization efforts did not depend on including every aspect of damage control work. NBCD can be safely added on in future analyses as necessary without disrupting the structure of the AH that has been developed in this project.

3.3.5 High Level AH Description

The AH of the damage control work domain is presented in Figure 3-2, below. It includes five levels of abstraction, as follows:

a. **Functional purpose.** The functional purpose level of this AH describes the purposes that the work system is intended to achieve. The first three functional purposes, Stability, Maneuverability, and Mission Effectiveness, are based on the slogan of the Damage Control Division of the CFNES: "to float, to move, to fight". In other words, the purpose of damage control is first to ensure that the ship is upright and stable, second to ensure that it can maneuver out of harm's

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[2] Evidence of this claim is the fact that the main information artefact for damage control, the incident board, includes every space on the entire ship, implying that damage control concerns span all spaces of the entire ship. On the other hand, the main information tool for CSEs, the CSE ERT pack, includes only information on spaces that include equipment for which the CSE organization is responsible.

way and/or to achieve its mission, and third, to ensure that the ship can be effective at its overall mission. These three purposes, however, do not describe this work system fully. It also operates within a broader societal, political, and moral sphere that impinges on it the three additional purposes of Personnel Safety, Environmental Protection, and Economic Stewardship. These three purposes describe social (Burns, 2004) or external (Naikar, *et al*. 2005) constraints. These constraints are more subjective than the others, but no less essential. The success of the damage control system requires that all purposes be met.

Abstract function. The abstract function level of this AH describes the fundamental principles for fulfilling each of the functional purposes. These range from the physical constraints imposed by requirements of Reserve buoyancy, Structural integrity, Positive righting arm, and List and trim, to the constraints imposed by the necessity of maintaining various capabilities (e.g., the Ability to achieve operational speed or the Ability to apply force), to value-based measures like Maximize health, Minimize environmental impact, and Minimize resource damages. While operators do not normally think about the work domain at this high level of abstraction, these abstract functions nonetheless describe the full set of principles on which the work system operates.

b. **Generalized function.** The generalized function level of this AH describes the ship properties and functions that the work system aims to preserve. For example, work in system must ensure that the ship's Freeboard, Watertight integrity, and Structural strength are preserved, that Load and balance are carefully monitored, and that ship systems (e.g. Internal communications or Targeting sensors) can be maintained in a functional state. All of this must be done while also enacting Protective measures, Spill prevention / containment, Resource allocation, Rapid response, and Prevention measures to ensure that the values of the system are also preserved. It should be noted that this level of the AH is intended to begin to describe the work domain in terms that are familiar to operators and that represent the considerations in mind during the usual conduct of their work.

c. **Physical function.** The physical function level of this AH makes a transition from describing ship functions to describing the types of damage control interventions that are available to restore those functions. Flood control is used to ensure that water external to the ship does not compromise the ship's functions, Fire containment and Fire suppression are used to ensure that uncontrolled combustion does not compromise ship functions, Ventilation is used to ensure that the ship's air is safe to breathe (or, in some situations, to suppress fires), and Power isolation is used to control ship's power generation and distribution system to support other physical functions and as a means to many of the generalized functions.

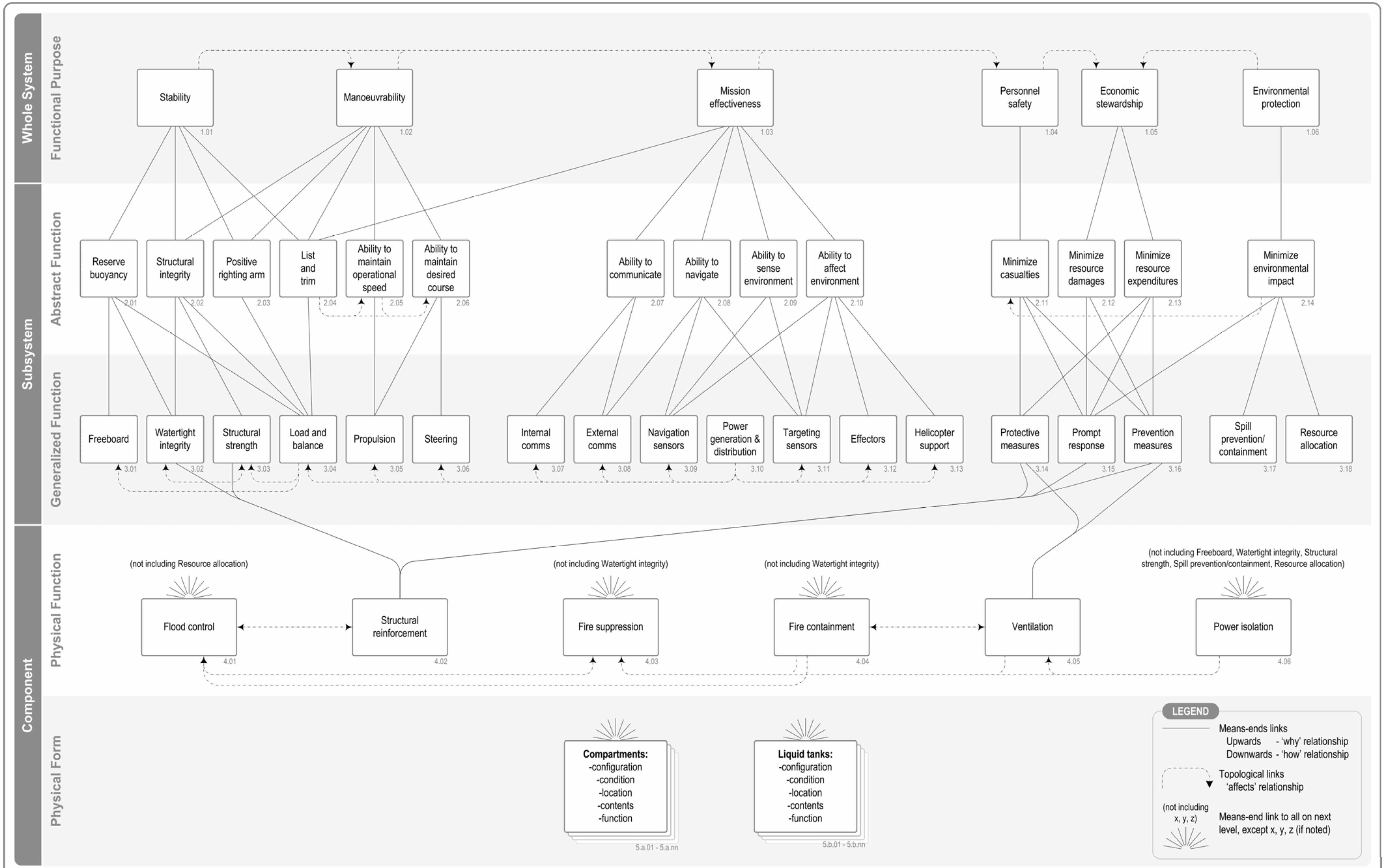

Figure 3-2. AH of the Damage Control Work Domain

d. **Physical form.** The physical form level of this AH includes all of the compartments and equipment on the ship, described in terms relevant to damage control. For example, this level describes each Compartment or Liquid Tank of the ship with respect to its location in the ship, adjacency relationships with other compartments, flooding and drainage considerations (e.g., vertical distance from the keel with respect to freeboard and location of eductor pumps), ventilation, contents, power supply, hazardous materials, and interconnections with ship systems (e.g. wiring). It should be noted that the AH presented in Figure 3-2 does not represent every ship compartment and liquid tank, but instead treats them generically. Given the scope of this project, it is not possible to describe all compartments in this way, but a sufficient number of compartments are fleshed out in Section 3.3.6.6.2 to show how this technique applies to the full range of compartment types.

Note that Figure 3-2 also indicates the decomposition level of each level of abstraction. The functional purposes level is at the whole system level of decomposition, the abstract and generalized function levels are at the subsystem level of decomposition, and the physical function and physical form levels are at the component level of decomposition. These levels of decomposition were identified after the initial AH was constructed, and then the AH was modified as appropriate to ensure that the items at each level of abstraction consistently referred to the same level of decomposition.

3.3.6 Detailed AH Description

3.3.6.1 Overview

In the sections that follow, the AH model of the object world of damage control within the ship system is described in full. The levels of the AH are presented with reference to their level of abstraction (functional purpose, abstract function, generalized function, physical function, or physical form) and their level of decomposition (whole system, subsystem, or component). Each node of the AH is presented as a table, and is numbered to correspond to the numbers at the bottom left corner of each node in the AH diagram in Figure 3-2. Each table includes the following four items:

a. **Description.** A brief description of the contents of the node.

b. **Ends.** Details of each end (i.e., upper-level links) that the node serves.

c. **Means.** Details of the means (i.e., lower-level links) that serve the node.

d. **Topological links.** Details of each node on the same level that are affected by the node.

For brevity and clarity, in what follows the term ‘work system’ should be read to mean ‘ship system from the perspective of the object world of damage control’.

3.3.6.2 Functional Purposes (Whole System Level)

The work system exists to maintain the conditions necessary for the survival and operational effectiveness of its host system, the ship. This central theme explains the trade-offs inherent in the five functional purposes.

The nodes of this level of the abstraction-decomposition space are as follows:

1.01 – Stability	
Description:	A *primary objective* of the work system is to ensure that the ship is stable, which means that it can float upright and right itself from a heel. Failure to meet this purpose means that the work system will not survive. This purpose is met primarily through physical constraints in the work system.
Ends:	None.
Means:	(2.01 – Reserve buoyancy) ***and*** (2.02 – Structural integrity) ***and*** (2.03 – Positive righting arm) ***and*** (2.04 – List and trim): These means must all be satisfied to achieve stability.
Topological links:	▪ **1.02 – Manoeuvrability.** Stability originating from a low center of gravity will limit manoeuvrability. ▪ **1.03 – Mission effectiveness.** Stability and floatation affect the mission readiness of the ship. ▪ **1.04 – Personnel safety.** An unstable or sinking ship could compromise the safety of the crew.

1.02 – Manoeuvrability	
Description:	A *primary objective* of the work system is to ensure that the ship can manoeuvre to the extent required by current circumstances. Failure to meet this purpose places the survival of the work system in jeopardy, making it vulnerable to both environmental disturbances and enemy action. This purpose is met primarily through physical constraints in the work system.
Ends:	None.
Means:	(2.02 – Structural integrity) ***and*** (2.03 – Positive righting arm) ***and*** (2.04 – List and trim) ***and*** (2.05 – Ability to achieve operational speed) ***and*** (2.06 – Ability to achieve desired course): These means must all be satisfied to achieve maximum manoeuvrability.
Topological links:	▪ **1.03 – Mission effectiveness.** Manoeuvrability allows for a degree of mission effectiveness for the ship. ▪ **1.04 – Personnel safety.** A ship that is manoeuvring aggressively could compromise the safety of the crew.

1.03 – Mission effectiveness	
Description:	A *primary objective* of the work system is to ensure that the ship will be effective on its current mission. Even if the ship is stable and is able to manoeuvre, failure to be effective in its specified mission means that the ship is functionally useless: warships are built to complete missions.
Ends:	None.

1.03 – Mission effectiveness	
Means:	(2.04 – List and trim) ***and*** ((2.07 – Ability to communicate) ***or*** (2.08 – Ability to navigate) ***or*** (2.08 – Ability to sense environment) ***or*** (2.10 – Ability to affect environment)): The mission capabilities required to conduct a specific mission must be maintained to conduct a mission effectively; many mission capabilities can only be maintained if the list and trim of the ship are within acceptable limits.
Topological links:	▪ **1.04 – Personnel safety.** A ship that is unable to carry out its mission effectively may compromise the safety of the crew.

1.04 – Personnel safety	
Description:	A *secondary objective* of the work system is safety of personnel on board the ship. The objective is secondary because it is sometimes necessary to compromise the safety of individuals to maintain mission effectiveness and save a ship (and, consequently, everyone on it). Safety of personnel is a value that is reflected primarily through intentional constraints, but also through physical constraints.
Ends:	None.
Means / criteria:	(2.13 – Minimize casualties): Damage control is inherently dangerous. Few or no injuries and deaths are an indicator that the work system is meeting its personnel safety objective. This includes injuries due to exposure to toxins in the workplace.
Topological links:	▪ **1.02 – Maneuverability.** A ship that is manoeuvring aggressively could compromise the safety of the crew. ▪ **1.04 – Economic stewardship.** Safety and economy will frequently be in conflict as the most effective means to safety will often be more expensive than less effective means.

1.05 – Economic stewardship	
Description:	A *secondary objective* of the work system is to satisfy financial constraints. Financial constraints can play an important role during the planning of operations, but less of a role during their execution (operators will generally use whatever resources are available to them without regard for their cost). Nonetheless, financial constraints on the execution of operations may be communicated through policies, procedures, etc.
Ends:	None.
Means:	(2.15 – Minimize resource damage) ***or*** (2.16 – Minimize resource expenditures): The work system meets its economic stewardship objective by minimizing damage that requires costly repairs. It can also achieve this objective by minimizing expenditures on resources consumed by the work system. These functions often conflict.
Topological links:	None.

1.06 – Environmental protection	
Description:	An *external constraint* on activity in the work system is the need to protect the environment from the ship system. This constraint is expressed in both law and societal norms. It is reflected in both the physical constraints designed into the system and the intentional constraints on its operation.
Ends:	None.
Means:	(2.14 – Minimize environmental impact): A work system that causes little or no environmental impact is an indicator that the system is meeting the environmental protection purpose.
Topological links:	▪ **1.05 – Economic stewardship**. Making environmental protection a constraint on operations may increase the overall cost of operations.

3.3.6.3 Abstract Functions (Subsystem Level)

The work system must trade-off resources described at the Generalized Function level to fulfill the Functional Purposes. The Abstract Function level allows a decision-maker to compare, prioritize, and direct resources towards the functional purposes (Naikar *et al*., 2005).

The nodes of this level of the abstraction-decomposition space are as follows:

2.01 – Reserve buoyancy	
Description:	The volume of the watertight portion of the ship above the waterline. If the reserve buoyancy is zero or negative the ship will sink. The greater the reserve buoyancy, the greater the separation between the state of the ship and this key survival boundary.
Ends:	▪ **1.01 – Stability.** Maintaining reserve buoyancy is the exclusive means to keeping the ship afloat.
Means:	(3.01 – Freeboard) ***and*** (3.02 – Watertight integrity) ***and*** (3.04 – Load and balance): Reserve buoyancy is achieved by ensuring that a positive freeboard is maintained, that the ship is not taking on water, and by managing ship loading.
Topological links:	None.

2.02 – Structural Integrity	
Description:	Structural integrity refers to the function of establishing and maintaining barriers between the ship and the environment, and between the spaces within the ship. With respect to the barrier between the ship and the environment, this function includes the criterion of maintaining the designed hull profile. With respect to internal barriers, this refers to maintaining separation between ship compartments.
Ends:	▪ **1.01 – Stability.** Maintaining structural integrity is a key means to stability. The ship cannot float unless it can establish barriers between spaces contributing to buoyancy and the sea. A ship with compartments partially exposed to the sea will be less stable due to the free communication effect between the water in the compartment and the sea. ▪ **1.02 – Manoeuvrability.** Disruptions to the designed hull profile will disrupt fluid flow around the ship, thereby affecting its manoeuvrability.
Means:	(3.02 - Watertight integrity) ***and*** (3.03 - Structural strength) ***and*** (3.04 - Load and balance): Hull breaches (a loss of watertight integrity) cause a reduction of structural strength, while reduced structural strength can cause hull breaches. Improper ship loading can also compromise structural integrity.
Topological links:	None.

2.03 – Positive righting arm	
Description:	The horizontal distance between the center of gravity and center of buoyancy of a ship. (Note that there are no instruments on the ship to directly measure righting arm; rather, this property is directly perceived by experienced operators.)
Ends:	▪ **1.01 – Stability.** The righting moment is proportional to the length of the righting arm. The righting moment acts to return the ship to an upright position as it heels. ▪ **1.02 – Manoeuvrability.** As a ship's righting arm is reduced the ship will become less responsive to the action of its rudder.
Means:	(3.04 - Load and Balance): The load and balance of the ship dictate the center of gravity.

2.03 – Positive righting arm	
Topological links:	None.

2.04 – List and trim	
Description:	List is the inclination of a ship relative to its longitudinal axis; trim is the inclination of a ship relative to its transverse axis. (Note that while there are instruments on the ship to measure list and trim, these properties are also directly perceived by operators.)
Ends:	▪ **1.01 – Stability.** As list and trim increase, a ship's stability is decreased. ▪ **1.02 – Manoeuvrability.** List and trim affect the way a ship moves through the water. For example, as list increases, it is more difficult to turn the ship. Also, as forward trim increases, the effectiveness of the ship's propellers and rudder are decreased. ▪ **1.03 – Mission effectiveness.** List and trim affect the functioning of certain mission systems. For example, list to port increases the amount a gun must depress to fire to starboard. As list or trim increases, some mission systems may not longer be able to function.
Means:	(3.04 – Load and balance): The positioning of loads on the ship induces list and trim.
Topological links:	▪ **2.05 – Ability to maintain operational speed.** As forward trim increases, the effectiveness of the ship's propellers is decreased. ▪ **2.06 – Ability to maintain desired course.** As list and trim increase, the ship becomes more difficult to steer.

2.05 – Ability to maintain operational speed	
Description:	To be able to manoeuvre, the ship must be able to meet the speed required by current operations.
Ends:	▪ **1.02 – Manoeuvrability**. Appropriate speed is one of two criteria that need to be met for the ship to be manoeuvrable.
Means:	(3.05 – Propulsion): Propulsion is required to gain and maintain operational speed.
Topological links:	▪ **2.06 – Ability to maintain desired course.** A ship can only maintain a desired course if it has steerage way, the speed required for the rudder to be able to properly steer the ship.

2.06 – Ability to maintain desired course	
Description:	To be able to manoeuvre, the ship must be able to maintain the course required by current operations (including any necessary course changes).
Ends:	▪ **1.02 – Manoeuvrability.** Prompt course changes are one of two measures of manoeuvrability.
Means:	(3.05 – Propulsion) ***or*** (3.06 – Steering): Although steering is the primary means to changing course, differential acceleration between the drive shafts can also be used to change the course of the ship.
Topological links:	None.

2.07 – Ability to communicate	
Description:	To be able to be mission capable, the ship must be able to communicate with external agencies and vessels. In addition, work teams on the ship must be able to communicate among themselves to coordinate their actions.

2.07 – Ability to communicate	
Ends:	▪ **1.03 – Mission effectiveness.** All ship missions involve communications.
Means:	(3.07 – Internal communications) ***and*** (3.08 – External communications): Both internal and external communications are required for the ship system to coordinate itself internally and with external agencies.
Topological links:	None.

2.08 – Ability to navigate	
Description:	To be mission capable, the ship must be able to move from place to place in an orderly and planned fashion.[3]
Ends:	▪ **1.03 – Mission effectiveness.** All ship missions involve navigation.
Means:	(3.06 – External communications) ***or*** (3.07 – Navigation sensors) ***or*** (3.11 – Targeting sensors): While navigation sensors are the prime means to the ability to navigate, targeting sensors can also be used for the same purpose. In the case where no sensors are available, external communications can allow a ship to use the navigation capabilities of other ships and agencies within communications range to help them to navigate.
Topological links:	None.

2.09 – Ability to sense environment	
Description:	To be mission capable, the ship must be able to sense and locate objects in the environment around it. This includes boats, aircraft, submarines, and missiles and other projectiles.
Ends:	▪ **1.03 Mission effectiveness.** Most ship missions involve a requirement to sense the environment, generally so that the environment can be avoided or affected.
Means:	(3.09 – Navigation sensors) ***or*** (3.11 – Targeting sensors): Navigation sensors and targeting sensors both afford the sensing of the environment.
Topological links:	None.

2.10 – Ability to affect environment	
Description:	To be mission capable, the ship must be able to affect the environment. This includes combat capabilities (e.g., weapons systems) and non-combat capabilities (e.g., boarding parties, divers).
Ends:	▪ **1.03 – Mission effectiveness.** Most ship missions involve a requirement to be able to affect the environment. Even if that capability is never used, it is important if only for its deterrent effect.
Means:	(((3.09 – Navigation sensors) **or** (3.11 – Targeting sensors)) **and** 3.12 – Effectors) **or** (3.13 – Helicopter support): The ship has various effectors, most of which must be used in conjunction with some sort of sensing capability (primarily targeting sensors, but navigation sensors can stand-in if necessary). The ship's helicopter is also another means to affecting the environment.

[3] Note that the ability to navigate is to be distinguished from functional purpose 1.02 – Manoeuvrability. Manoeuvrability speaks to the physical ability to make course changes and hold a course; navigation speaks to the planning ability to determine which course should be followed.

2.10 – Ability to affect environment	
Topological links:	None.

2.11 Minimize casualties	
Description:	Casualties include injuries and deaths sustained by the crew, both in the short term and over the long term.
Ends:	▪ **1.04 - Personnel safety.** The personnel safety purpose can only be maintained if minimal casualties are sustained by the crew.
Means:	(3.14 - Protective measures) ***or*** (3.15 - Prompt Response) ***or*** (3.16 – Preventive Measures): Casualties are minimized through the effective application of protective and preventive measures and timely response to emergencies. Note that timely response applies to both the Rapid Response and Deliberate Response modes. In both cases, casualties are minimized by these actions being taken promptly.
Topological links:	None.

2.12 – Minimize resource damages	
Description:	Damage to resources on the ship can lead to costly repairs or replacement.
Ends:	▪ **1.05 - Economic stewardship.** Minimizing resource damages helps the ship system to operate within its financial constraints.
Means:	(3.15 - Prompt response) ***or*** (3.16 - Prevention measures): Resource damage can be prevented either by responding to damage promptly or by preventing the damage from occurring in the first place.
Topological links:	None.

2.13 – Minimize resource expenditures	
Description:	The day-to-day operation of naval ships is expensive, but decisions can be made that minimize those expenses.
Ends:	▪ **1.06 - Economic stewardship.** Minimizing the amount of resources expended operations helps the ship system to operate within its financial constraints.
Means:	(3.14 – Protective measures) ***or*** (3.15 - Prompt response) ***or*** (3.16 - Prevention measures): A prompt response to damage or damage prevention measures can help to minimize the resources expended to control damage. These means each have cost implications that need to be traded off against one another to minimize resource expenditures.
Topological links:	None.

2.14 – Minimize environmental impact	
Description:	Work strategies should be chosen so as to prevent or limit deleterious environmental impacts.
Ends:	▪ **1.05 - Environmental stewardship.** The purpose of stewardship is considered to be met if environmental impact is kept within legal constraints and societal norms.

2.14 – Minimize environmental impact	
Means:	(3.17 - Spill prevention/containment) ***or*** (3.18 - Resource allocation) ***or*** (3.15 - Prompt response): Environmental impacts are minimized by preventing spills of hazardous materials, or by containing such spills where they occur, or by employing resources that do not pose a threat if released into the environment. Also, prompt response to emergencies will limit impact on the environment, as will prevention measures.
Topological links:	▪ **2.11 – Minimize casualties.** It is frequently the case that if decisions are made to minimize environmental impact, this will result in benefits to crew health (for example, choosing paints that are not lead-based minimizes environmental impact and eliminates the chance of casualties due to breathing in the noxious fumes from burning lead-based paints). Conversely, some decisions that minimize environmental impact (for example, not using Halon) may increase the potential for casualties.

3.3.6.4 Generalized Functions (Subsystem Level)

This level of the abstraction-decomposition space describes functions necessary to fulfill the purposes of the work system as a set of high-level ship subsystems and processes. This level of the model describes the abstract functions in the previous level in high-level, yet more granular terms that operators of the system may use as a part of their everyday work.

The nodes of this level of the abstraction-decomposition space are as follows:

3.01 – Freeboard	
Description:	The distance between the waterline and the top of the watertight structure of the ship.
Ends:	▪ **2.01 - Reserve buoyancy.** While freeboard is not equivalent to reserve buoyancy, it is directly correlated to it. It is the concept that operators use to operationalize reserve buoyancy.
Means:	(4.01 - Flood control) ***or*** (4.03 – Fire suppression) ***or*** (4.04 – Fire containment): Freeboard will be reduced by flooding, both because the ingress of water causes a loss of reserve buoyancy and because hull breaches effectively reduce freeboard to zero. The controlled ingress of water into the ship in support of Fire control and Fire suppression may also cause a loss of freeboard.
Topological links:	None.

3.02 – Watertight integrity	
Description:	The process of preventing the flow of water through a barrier.
Ends:	▪ **2.01 - Reserve buoyancy.** If water is able to flow into the ship through a hull breach, reserve buoyancy is lost. ▪ **2.02 - Structural integrity.** Hull breaches can cause a loss of structural strength that can compromise structural integrity.
Means:	(4.01 - Flood control) ***and*** (4.02 - Ventilation): To maintain watertight integrity, flooding must be controlled and ventilation sources must be sealed.
Topological links:	▪ **3.03 – Structural strength.** Water acts as a load on structures.

3.03 – Structural strength	
Description:	The ability of the ship structure to withstand loads of various types.

3.03 – Structural strength	
Ends:	▪ 2.02 - Structural Integrity
Means:	(4.01 - Flood Control) ***and*** ((4.03 - Fire Suppression) ***or*** (4.04 - Fire Containment)): Structural strength is reduced by fire, therefore suppression or containment will preserve structural strength. Structures are placed under stress by flooding. Thus, flood control will preserve structural strength.
Topological links:	▪ **3.02 – Watertight Integrity**. The loads on the ship's hull or on any bulkheads adjacent to compartments that have flooded must not exceed their designed strength if the ship is to maintain watertight integrity.

3.04 – Load and balance	
Description:	The dry and liquid loads on a ship must be balanced to maintain the ship's attitude in the water as well as reserve buoyancy. In addition, loads that are too large or poorly balanced can compromise a ship's structural integrity.
Ends:	▪ **2.01 - Reserve buoyancy.** As loading increases, reserve buoyancy is decreased. ▪ **2.02 – Structural integrity.** Excessive or poorly balanced loads can compromise a ship's structural integrity. ▪ **2.03 – Positive righting arm.** Poorly balanced loads can shorten a ship's positive righting arm. ▪ **2.04 – List and trim.** Poorly balanced loads can induce list and trim.
Means:	(4.01 - Flood control) ***and*** (4.03 - Fire suppression) ***and*** (4.04 - Fire containment): Water inside the ship (through flooding and/or fire fighting) acts as a load that may affect the balance of the ship.
Topological links:	▪ **3.01 – Freeboard.** As loading increases, freeboard is decreased. ▪ **3.03 – Structural Strength.** Excessive loads in one area of the ship may cause breakages that compromise the structural strength of other parts of the ship.

3.05 – Propulsion	
Description:	The process of creating motive power.
Ends:	▪ **2.05 - Ability to Achieve Operational Speed.** Some form of propulsion is required to achieve operational speed. ▪ **2.06 – Ability to Achieve Desired Course.** The configuration of the propulsion sources can be varied to achieve course changes.
Means:	(4.02 – Ventilation) ***and*** ((4.03 - Fire suppression) ***or*** (4.04 - Fire containment)) ***and*** (4.06 – Power isolation): Propulsion sources require oxygen, which is provided by ventilation. Fires consume oxygen, can damage propulsion sources, and can make the machinery spaces unsafe for the personnel required to operate and maintain them. Propulsion sources on the ship require power for long-term operation, and so can be affected by changes in the power system caused by Power isolation efforts. **Note:** Propulsion has further means (e.g., engines) that are within the system boundary but that are not part of the damage control object world.
Topological links:	None.

3.06 – Steering	
Description:	The process of directing the course of the ship.
Ends:	▪ **2.06 - Ability to achieve desired course:** Steering is the primary means of achieving the desired course.

3.06 – Steering	
Means:	(4.02 – Ventilation) ***and*** ((4.03 - Fire suppression) ***or*** (4.04 - Fire containment)) ***and*** (4.06 – Power isolation): Fires can damage steering equipment and produce noxious gases which must be ventilated in order for steering spaces remain manned. Steering systems require power for long-term operation, and so can be affected by changes in the power system caused by Power isolation efforts. **Note:** Steering has further means (e.g., rudder) that are within the system boundary but that are not part of the damage control object world.
Topological links:	▪ None

3.07 – Internal communications	
Description:	Internal communications provide the ability to communicate with personnel internal to the ship.
Ends:	▪ **2.07 – Ability to communicate.** Internal communications are an important part of the ship's overall requirement to be able to communicate.
Means:	(4.01 – Flood control) ***or*** (4.03 – Fire suppression) ***or*** (4.04 – Fire containment) ***or*** (4.06 – Power isolation): Floods and fires can impair the ship's internal communications equipment, either due to the floods or fires themselves, or because of power isolation in support of fire containment. **Note:** Internal communications has further means (e.g., ship's intercom system) that are within the system boundary but that are not part of the damage control object world.
Topological links:	None.

3.08 – External communications	
Description:	External communications provide the ability to communicate with vessels and agencies external to the ship.
Ends:	▪ **2.07 – Ability to communicate.** External communications are an important part of the ship's overall requirement to be able to communicate. ▪ **2.08 – Ability to navigate.** External communications can also be used in support of navigation when other means of navigation are not available.
Means:	(4.01 – Flood control) ***or*** (4.03 – Fire suppression) ***or*** (4.04 – Fire containment) ***or*** (4.06 – Power isolation): Floods and fires can impair the ship's external communications equipment, either due to the floods or fires themselves, or because of power isolation in support of fire containment. **Note:** External communications has further means (e.g., V/UHF radios) that are within the system boundary but that are not part of the damage control object world.
Topological links:	None.

3.09 – Navigation sensors	
Description:	Navigation sensors provide the ability to sense the environment in a way that affords navigation.
Ends:	▪ **2.08 – Ability to navigate.** Navigation sensors are the primary means to this end. ▪ **2.09 – Ability to sense environment.** Navigation sensors provide an important picture of the environment. ▪ **2.10 – Ability to affect environment.** Navigation sensors can be used as a secondary means for the sensing capabilities required to affect the environment.

3.09 – Navigation sensors	
Means:	(4.01 – Flood control) ***or*** (4.03 – Fire suppression) ***or*** (4.04 – Fire containment) ***or*** (4.06 – Power isolation): Floods and fires can impair the ship's navigation sensors, either due to the floods or fires themselves, or because of power isolation in support of fire containment. **Note:** Navigation sensors have further means (e.g., GPS) that are within the system boundary but that are not part of the damage control object world.
Topological links:	None.

3.10 – Power generation & distribution	
Description:	Power generation & distribution (**PG&D**) is a critical service that supplies all mission systems with electrical power.
Ends:	None. PG&D is an important service, but is not explicitly included in the Subsystem – Abstract function level of this AH.
Means:	(4.01 – Flood control) ***or*** (4.03 – Fire suppression) ***or*** (4.04 – Fire containment) ***or*** (4.06 – Power isolation): Floods and fires can impair the ship's PG&D subsystem, either due to the floods or fires themselves, or because of power isolation in support of fire containment. **Note:** PG&D has further means (e.g., switchboards) that are within the system boundary but that are not part of the damage control object world.
Topological links:	▪ **3.04 – Load and balance.** PG&D is required by the pumps that remove excess water from the ship. ▪ **3.05 – Propulsion.** PG&D is required by the propulsion subsystems. ▪ **3.06 – Steering.** PG&D is required by the steering subsystems. ▪ **3.07 – Internal communications.** PG&D is required by the internal communications subsystems. ▪ **3.08 – External communications.** PG&D is required by the external communications subsystems. ▪ **3.09 – Navigation sensors.** PG&D is required by the navigation sensor subsystems. ▪ **3.11 – Targeting sensors.** PG&D is required by the targeting sensor subsystems. ▪ **3.12 – Effectors.** PG&D is required by the ship's effectors. ▪ **3.13 – Helicopter support.** PG&D is required by ship's hangar.

3.11 – Targeting sensors	
Description:	Targeting sensors provide the ability to sense the environment in a way that affords affecting the environment (especially with weapons).
Ends:	▪ **2.08 – Ability to navigate.** Targeting sensors can assist in navigation if the primary navigation sensors are not available. ▪ **2.09 – Ability to sense environment.** Targeting sensors provide an important picture of the environment. ▪ **2.10 – Ability to affect environment.** The picture of the environment provided by targeting sensors is tailored to the missions systems for affecting the environment.

3.11 – Targeting sensors	
Means:	(4.01 – Flood control) ***or*** (4.03 – Fire suppression) ***or*** (4.04 – Fire containment) ***or*** (4.06 – Power isolation): Floods and fires can impair the ship's targeting sensors, either due to the floods or fires themselves, or because of power isolation in support of fire containment. **Note:** Targeting sensors have further means (e.g., long-range surveillance radars) that are within the system boundary but that are not part of the damage control object world.
Topological links:	None.

3.12 - Effectors	
Description:	Effectors provide the ability to project the ship's capabilities out into the environment around the ship. This includes weapons subsystems and non-combat subsystems (like diving or boarding).
Ends:	▪ **2.10 – Ability to affect environment.** Effectors are the ship's primary means for affecting the environment.
Means:	(4.01 – Flood control) ***or*** (4.03 – Fire suppression) ***or*** (4.04 – Fire containment) ***or*** (4.06 – Power isolation): Floods and fires can impair the ship's effectors, either due to the floods or fires themselves, or because of power isolation in support of fire containment. **Note:** Effectors have further means (e.g., torpedo system) that are within the system boundary but that are not part of the damage control object world.
Topological links:	None.

3.13 – Helicopter support	
Description:	The CPF is capable of hosting a military helicopter (currently, the Sea King; in the near future, the H-92) along with its crew detachment. The CPF's helicopter support includes all ship subsystems and fittings intended to support the attached helicopter as well as the helicopter itself.
Ends:	▪ **2.10 – Ability to affect environment.** Helicopter support is an important way for the CPF to affect the environment, especially in anti-submarine warfare (**ASW**) missions where helicopters are able to deploy sonobuoys and torpedoes.
Means:	(4.01 – Flood control) ***or*** (4.03 – Fire suppression) ***or*** (4.04 – Fire containment) ***or*** (4.06 – Power isolation): Floods and fires can impair the ship's helicopter support, either due to the floods or fires themselves, or because of power isolation in support of fire containment. **Note:** Helicopter support has further means (e.g., RAST system) that are within the system boundary but that are not part of the damage control object world.
Topological links:	None.

3.14 – Protective measures	
Description:	The process of establishing barriers between people and sources of harm. These include protective clothing and smoke curtains, or fitted fire control systems that do not require the human operators.
Ends:	▪ **2.11 - Minimize casualties.** Protective measures are an important means toward the minimization of casualties.

3.14 – Protective measures	
Means:	(4.01 - Flood Control) ***or*** (4.02 – Structural Reinforcement) ***or*** (4.03 - Fire Suppression) ***or*** (4.04 -Fire Containment) ***or*** (4.05 - Ventilation) ***or*** (4.08 - Power Isolation): All methods of damage control can employ protective measures that will distance personnel from substances, sources of energy, or situations than can cause harm. Ventilation and Power isolation can both be considered as protective measures that make spaces amenable to other damage control interventions or ship functions (e.g., Power isolation will allow fires in a 440V space to be fought with water, and Ventilation helps to allow CSEs to quickly enter a space for repairs).
Topological links:	None.

3.15 – Prompt response	
Description:	The process of responding quickly to flooding, fire, loss of power, etc.
Ends:	▪ **2.11 – Minimize casualties.** A prompt response can ensure that damage is dealt with when it is small, easily controlled, and relatively harmless. ▪ **2.12 - Minimize resource damages.** A prompt response can minimize the amount of resources affected by damage. ▪ **2.13 - Minimize resource expenditures.** A prompt response can minimize the amount of resources expended to control damage. ▪ **2.14 – Minimize environmental impact.** A prompt response can minimize the chance that damage creates any environmental impact.
Means:	(4.01 - Flood control) ***or*** (02 – Structural reinforcement) ***or*** (4.03 - Fire suppression) ***or*** (4.04 -Fire containment) ***or*** (4.08 - Power isolation): Each of these physical functions can be planned or conducted in such a way as to afford a prompt response.
Topological links:	None.

3.16 – Prevention measures	
Description:	The process of preventing damage or the propagation of damage.
Ends:	▪ 2.12 - Minimize resource damages ▪ 2.13 - Minimize resource expenditures
Means:	(4.01 - Flood control) ***or*** (4.02 – Structural reinforcement) ***or*** (4.03 - Fire suppression) ***or*** (4.04 -Fire containment) ***or*** (4.05 - Ventilation) ***or*** (4.08 - Power isolation): All of these damage control functions can be performed prior to damage being incurred to either prevent damage or to limit its effects and propagation. This includes decisions made during procurement for the design of ship systems that are able to prevent damage or its propagation.
Topological links:	None.

3.17 – Spill prevention / containment	
Description:	The processes of preventing or containing spills of hazardous materials.
Ends:	▪ **2.14 - Minimize environmental impact.** One of the chief ways in which the ship can harm the environment is by spilling untreated bilge water or fuel. Preventing and containing spills are important means to this end.

3.17 – Spill prevention / containment	
Means:	(4.01 - Flood control) ***or*** (4.03 -Fire suppression) ***or*** (4.04 - Fire containment): Fire suppression and fire containment can be performed in ways that minimize the amount of contaminated water that enters the bilges; flood control can be performed to delay the need to return bilge water to the sea.
Topological links:	None.

3.18 – Resource allocation	
Description:	The processes of selecting and employing resources that pose the smallest threat to the environment.
Ends:	▪ 2.14 - Minimize environmental impact
Means:	(4.03 - Fire suppression) ***or*** (4.04 - Fire Containment): There may be many strategies for performing each of these damage control functions, each using different substances with varying potential impact on the environment. For instance, different fire suppression strategies may employ different chemical based fire suppression agents.
Topological links:	None.

3.3.6.5 Physical Functions (Component Level)

This level of the abstraction-decomposition space typically describes the components of the work domain and their capabilities (Burns & Hajdukiewicz, 2004). For the object world of damage control, the level of physical functions is notable because it describes the capabilities of the work system to respond to incidents of damage, either proactively or retroactively. While at first this may not seem to be a more granular description of the generalized function level, when viewed from the perspective of the object world of damage control, it really is: damage control involves exercising a mix of core capabilities across the ship to respond to damage so that the generalized and abstract functions of the work system can be maintained in service of the ship's functional purposes.

The nodes of this level of the abstraction-decomposition space are as follows:

4.01 – Flood control	
Description:	The capabilities for preventing flooding and for removing water from the ship.

4.01 – Flood control	
Ends:	▪ **3.01 – Freeboard.** Flood control can increase the ship's freeboard. ▪ **3.02 – Watertight integrity.** Flood control can use jury-rig solutions to restore the ship's watertight integrity. ▪ **3.03 – Structural strength.** Flood control relieves the strain on ship bulkheads by removing water from the ship. ▪ **3.04 – Load and balance.** Flood control decisions (i.e., to lose a compartment to sea; to allow a compartment to remain partially filled with water, to pump water from one bilge to another, or to pump water off of the ship) affect the overall load and balance situation of the ship. ▪ **3.05 – Propulsion, 3.06 – Steering, 3.07 – Internal communications, 3.08 – External communications, 3.09 – Navigation sensors, 3.10 - Power generation and distribution, 3.11 – Targeting sensors, 3.12 – Effectors, 3.13 – Helicopter support.** Flood control can restore spaces of the ship that provide for any of these functions so that (if necessary) repair teams of CSEs can repair any damaged equipment and the systems can be returned to their normal functioning status. ▪ **3.14 – Protective measures.** Flood control can be performed in ways that are more or less potentially harmful to humans responsible for flood control. ▪ **3.15 – Prompt response.** Flood control efforts can be organized and carried out to provide a more or less prompt response to floods. ▪ **3.16 – Prevention measures.** Flood control can reconfigure ship's hatches or set up equipment to proactively respond to anticipated damage. The ship's hull can also be designed in such a way to prevent floods or to make the overall ship system less sensitive to flooding. ▪ **3.17 – Spill prevention/containment.** A key role of flood control is to deal with excess water in ways that prevent or contain the amount of contaminated water to be spilled into the environment.
Means:	▪ **5.a.01-5.b.nn – Compartments.** The configuration, condition, location, contents, and function of each of the ship's compartments (from 01 to nn) provide affordances for flood control. ▪ **5.b.01-5.1.nn – Liquid tanks.** The configuration, condition, location, contents, and function of each of the ship's liquid tanks (from 01 to nn) provide affordances for flood control.
Topological links:	▪ **4.02 – Structural reinforcement.** Flood control can alleviate the causes of excessive structural loading and so can reduce the requirement for structural reinforcement. ▪ **4.03 – Fire suppression.** Fire suppression with water or liquid agents effectively causes flooding; conversely, due to concern for flooding, it may not be wise to suppress a fire.

4.02 – Structural reinforcement	
Description:	The capabilities for shoring up and otherwise reinforcing structures that are currently or may in the future experience excessive loads, generally due to flooding.

4.02 – Structural reinforcement	
Ends:	▪ **3.02 – Watertight integrity.** Structural reinforcement helps to maintain a new watertight configuration of the ship once one or more compartments have been lost to sea. ▪ **3.14 – Protective measures.** Structural reinforcement can be performed in ways that are more or less potentially harmful to humans responsible for flood control. ▪ **3.15 – Prompt response.** Structural reinforcement efforts can be organized and carried to provide a more or less prompt response to structural problems. ▪ **3.16 – Prevention measures.** Structural reinforcement can shore up bulkheads proactively in anticipation of damage; structures can also be reinforced at design time to make them less susceptible to breakage.
Means:	▪ **5.a.01-5.b.nn – Compartments.** The configuration, condition, location, contents, and function of each of the ship's compartments (from 01 to nn) provide affordances for structural reinforcement. ▪ **5.b.01-5.1.nn – Liquid tanks.** The configuration, condition, location, contents, and function of each of the ship's liquid tanks (from 01 to nn) provide affordances for structural reinforcement.
Topological links:	▪ **4.01 – Flood control.** Structural reinforcement can prevent the advance of floods across the ship, thus reducing the need for flood control.

4.03 – Fire suppression	
Description:	The capability for reducing the extent of and extinguishing fires on the ship.
Ends:	▪ **3.03 – Structural strength.** The heat of a fire can reduce the strength of a bulkhead, and can even cause some types of bulkheads (e.g., aluminium) to burn. Extinguishing fires reduces heat and can restore the strength of bulkheads. ▪ **3.05 – Propulsion, 3.06 – Steering, 3.07 – Internal communications, 3.08 – External communications, 3.09 – Navigation sensors, 3.10 – Power generation and distribution, 3.11 – Targeting sensors, 3.12 – Effectors, 3.13 – Helicopter support.** Fire suppression can restore spaces of the ship that provide for any of these functions so that (if necessary) repair teams of CSEs can repair any damaged equipment and the systems can be returned to their normal functioning status. ▪ **3.14 – Protective measures.** Fire suppression can be performed in ways that are more or less potentially harmful to humans responsible for this function. ▪ **3.15 – Prompt response.** Fire suppression efforts can be organized and carried to provide a more or less prompt response to fires. ▪ **3.16 – Prevention measures.** Fire suppression includes design time efforts to fit compartments with systems that will automatically respond to fires, or to create environments in which fires will not burn (i.e., oxygen free compartments). ▪ **3.17 – Spill prevention/containment.** The water used in fire suppression often ends up as contaminated water in the ship's bilges. In addition, fire suppression often uses additional chemical agents for suppressing fires that cannot be directly dumped into the sea. ▪ **3.18 – Resource allocation.** Fire suppression efforts may use resources that are more or less costly.
Means:	▪ **5.a.01-5.b.nn – Compartments.** The configuration, condition, location, contents, and function of each of the ship's compartments (from 01 to nn) provide affordances for fire suppression. ▪ **5.b.01-5.1.nn – Liquid tanks.** The configuration, condition, location, contents, and function of each of the ship's liquid tanks (from 01 to nn) provide affordances for fire suppression.

4.03 – Fire suppression	
Topological links:	▪ **4.01 – Flood control.** Fire suppression with water or liquid agents effectively causes flooding; conversely, due to concern for flooding, it may not be wise to suppress a fire.

4.04 – Fire containment	
Description:	The capability of preventing the spread of a fire by containing it to a region of the ship.
Ends:	▪ **3.03 – Structural strength.** The heat of a fire can reduce the strength of a bulkhead, and can even cause some types of bulkheads (e.g., aluminium) to burn. Fire containment actively works to lower the heat of bulkheads adjacent to fires, and prevents the spread of fires to additional bulkheads. ▪ **3.05 – Propulsion, 3.06 – Steering, 3.07 – Internal communications, 3.08 – External communications, 3.09 – Navigation sensors, 3.10 – Power generation and distribution, 3.11 – Targeting sensors, 3.12 – Effectors, 3.13 – Helicopter support.** Fire containment can prevent fires from spreading to spaces of the ship that provide for any of these functions. ▪ **3.14 – Protective measures.** Fire containment can be performed in ways that are more or less potentially harmful to humans responsible for this function. ▪ **3.15 – Prompt response.** Fire containment efforts can be organized and carried to provide a more or less prompt response to fires. ▪ **3.16 – Prevention measures.** Fire containment efforts involve proactively wetting down compartments (or, in the case of ammunition magazines, flooding them) to prevent the spread of fire across the ship. ▪ **3.17 – Spill prevention/containment.** The water used in fire containment often ends up as contaminated water in the ship's bilges. ▪ **3.18 – Resource allocation.** Fire containment efforts may use resources that are more or less costly.
Means:	▪ **5.a.01-5.b.nn – Compartments.** The configuration, condition, location, contents, and function of each of the ship's compartments (from 01 to nn) provide affordances for fire containment. ▪ **5.b.01-5.1.nn – Liquid tanks.** The configuration, condition, location, contents, and function of each of the ship's liquid tanks (from 01 to nn) provide affordances for fire containment.
Topological links:	▪ **4.01 – Flood control.** Fire containment with water effectively causes flooding; conversely, due to concern for flooding, it may not be wise to contain a fire with water. ▪ **4.03 – Fire Suppression**. A fire cannot be suppressed until it is contained. ▪ **4.05 – Ventilation.** To suppress a fire, ventilation sources to the area with the fire must be turned off or blocked.

4.05 - Ventilation	
Description:	The capability for providing air to spaces within the vessel and for evacuating gasses from within the vessel. Not included are air intake and exhaust for propulsion.
Ends:	▪ **3.14 – Protective measures.** Ventilation helps to ensure that spaces within the ship do not contain gases that might be harmful to humans. ▪ **3.16 – Prevention Measures.** If ventilation to an area is reduced or eliminated, it will be easier to suppress or contain the fire in that area.

4.05 - Ventilation	
Means:	▪ **5.a.01-5.b.nn – Compartments.** The configuration, condition, location, contents, and function of each of the ship's compartments (from 01 to nn) provide affordances for ventilation. ▪ **5.b.01-5.1.nn – Liquid tanks.** The configuration, condition, location, contents, and function of each of the ship's liquid tanks (from 01 to nn) provide affordances for ventilation.
Topological links:	▪ **4.03 – Fire suppression, 4.04 – Fire containment.** If ventilation to spaces containing fires is on or free, oxygen will be provided to the fire, feeding it. Conversely, if ventilation to spaces containing fires is off or blocked, the fire will be starved from oxygen and will quickly extinguish.

4.06 – Power isolation	
Description:	The capability for isolating spaces of the ship from power sources to allow the fires in those areas to be suppressed with water-based agents.
Ends:	▪ **3.04 – Load and balance.** Power isolation can cause a loss of capability to pump liquid loads around the ship or water out of the ship. ▪ **3.05 – Propulsion.** Power isolation can cause the loss of propulsion subsystems. ▪ **3.06 – Steering.** Power isolation can cause the loss of steering subsystems. ▪ **3.07 – Internal communications.** Power isolation can cause the loss of internal communications subsystems. ▪ **3.08 – External communications.** Power isolation can cause the loss of external communications subsystems. ▪ **3.09 – Navigation sensors.** Power isolation can cause the loss of navigation sensor subsystems. ▪ **3.10 - Power generation and distribution.** Power isolation can have broad impacts in terms of power loading across the PG&D subsystem. ▪ **3.11 – Targeting sensors.** Power isolation can cause the loss of targeting sensor subsystems. ▪ **3.12 – Effectors.** Power isolation can cause the loss of effectors. ▪ **3.13 – Helicopter support.** Power isolation can cause the loss of helicopter support. ▪ **3.14 – Protective measures.** Power isolation can make it safe for personnel to fight fires in 440V electrical spaces with water-based agents. ▪ **3.15 – Prompt response.** Rapid power isolation can enable rapid fire suppression and containment. ▪ **3.16 – Prevention measures.** Power isolation can help to prevent water-based fire suppression agents from damaging equipment in spaces that are on fire.
Means:	▪ **5.a.01-5.b.nn – Compartments.** The configuration, condition, location, contents, and function of each of the ship's compartments (from 01 to nn) provide affordances for power isolation. ▪ **5.b.01-5.1.nn – Liquid tanks.** The configuration, condition, location, contents, and function of each of the ship's liquid tanks (from 01 to nn) provide affordances for power isolation.
Topological links:	▪ **4.03 – Fire suppression.** The pumps that deliver water to fires require power to function. In addition, power isolation can make it possible to suppress fires in spaces with 440V power. ▪ **4.05 – Ventilation.** Forced ventilation subsystems require power to operate.

3.3.6.6 Physical Form (Component Level)

This level of the AH typically describes the work system at the level of exact physical forms, including considerations such as configuration, location, condition, etc., to communicate the exact physical details of the work system. This level of description is important for ship system from the perspective of the object world of damage control, because it describes the affordances of each compartment in terms relevant to damage control. However, the CPF has far too many compartments to make practical a precise description of the physical forms in each and every compartment. Instead, for the purposes of this project, a small number of compartments representing the different types of spaces on the CPF were chosen as test cases to show that a description of the physical forms of each compartment is possible. Later phases of this project (especially the construction of the IPME simulation) will need to construct similar descriptions of the physical forms implicated in damage control scenarios to be developed in the second phase.

3.3.6.6.1 Compartment Selection Criteria

Although the CPF is made up of many different compartments, they can generally be classified into a number of common types of spaces. Interviews with SMEs revealed that the operators generally break down the compartments on the CPF into the following eight classifications:

a. **Magazines.** Compartments that hold explosive weapons. These compartments pose a large risk of explosions should they experience a fire.

b. **Stores.** Compartments that hold goods such as food, beverages, and other miscellaneous supplies. These compartments do not generally pose an important damage control risk, but if damage in these compartments is not dealt with important ship resources can be lost.

c. **Electrical/Electronics – 440 Volts.** Compartments that are supplied by 440V power. These compartments pose a special damage control risk because it is not safe for personnel to fight a 440V fire with water-based agents. In addition, equipment served by 440V power is typically important equipment from a mission effectiveness perspective, or costly equipment.

d. **Electronics – 120 Volts.** Compartments that are supplied by 120V power and that contain important ship electronics. Even though personnel can safely fight 120V fires with water-based agents, these compartments involve special damage control considerations because they contain equipment that is important from a mission effectiveness perspective.

e. **Habitability.** Compartments that are used for general crew activities, such as messes and bunks. These compartments do not generally pose an important damage control risk, but they generally house personnel whose safety may be compromised by damage sustained.

f. **Machinery.** Compartments that house ship machinery. These compartments pose a special damage control risk because fires in them are fuel-based fires which require special fire suppression resources (typically a water-based agent called Aqueous Film Forming Foam, or A-triple-F). In addition, these spaces typically use 440V power. Finally, they generally contain equipment that is important from a mission effectiveness perspective.

g. **Workshops – 440 Volts.** Compartments used for maintenance functions that include 440V power. These compartments pose a special damage control risk because it is not safe for personnel to fight a 440V fire with water-based agents. In addition, workshops typically contain costly equipment.

h. **Workshops – 120 Volts.** Compartments used for maintenance functions that include 120V power. Even though personnel can safely fight 120V fires with water-based agents, these compartments typically contain costly equipment.

Compartments on the CPF can also be classified by location. The CPF is also made up of watertight subdivisions that are formed by main transverse bulkheads and decks. The watertight subdivisions are indicated by sections using the letters A through M (from bow to stern), and by decks, from 02 and 01 for the superstructure, to 1 through 6 for the decks within the hull.

To construct a representative sample of spaces to model at the physical form level, at least one compartment was selected for each type of space while at the same time trying to cover as many of the watertight subdivisions as possible. As a result, compartments were selected as shown in Table 3-1, below:

Compartment	Type	Location
Command and Control Equipment Room No. 4	Electronics – 120 Volts	Deck 4, Section C
Control Systems Workshop	Workshop – 120 Volts	Deck 3, Section G
Crew's Lounge	Habitability	Deck 3, Section D
Forward Engine Room	Machinery	Deck 6, Section F
Forward Switchboard	Electrical – 440 Volts	Deck 2, Section E
General Store No. 2	Stores	Deck 4, Section K
Paint Store	Stores	Deck 2, Section A
Port Torpedo Magazine	Magazine	Deck 1, Section H
Radar Room No. 2	Electronics – 440 Volts	Deck 2, Section D
Ship's Laundry	Habitability	Deck 4, Section J
Shipwright's Workshop	Workshop – 120 Volts	Deck 2, Section L
Steering Gear Compartment	Machinery	Deck 3, Section M

Table 3-1. Compartments selected for modelling at the physical form level of abstraction.

Fluid tanks were not considered at the physical form level because they have been designed in such a way as to be protected from most damage. SMEs consulted were of the opinion that liquid tanks are not relevant from a damage control perspective, except for the fact that they have an important effect on load and balance.

These compartments are described in what follows. While the other nodes in the AH were described with respect to their means, ends, and topological linkages, the selected compartments are described with a greater emphasis on their affordances for damage propagation and control in general as well as their affordances with respect to the various generalized functions of the ship system.[4] Each description includes the following items:

a. **Description.** A brief overview of the compartment and its overall purpose.

b. **Location and adjacency.** Details of the location of the compartment within the ship as well as its adjacency to other compartments. (Where diagrams demonstrating adjacency were available, they have been included.)

c. **Access.** The ways in which access is provided to the compartment.

d. **Flooding / drainage.** The characteristics of the compartment relevant to flooding and drainage including its location vis à vis the typical ship waterline.

e. **Ventilation.** The ways in which ventilation is provided to the compartment.

f. **Contents.** The typical contents of the compartment, from which generalized functions served by the compartment can be abstracted.

g. **Power considerations.** The power supply to the compartment.

h. **Hazardous materials.** Any contents of the compartment that might pose a special risk either because they are volatile (e.g., explosives) or potentially hazardous to human health (e.g., batteries).

i. **System interconnections.** Details of the wires and conduits passing through the compartment that are at risk of being compromised if damage is sustained to the compartment.

3.3.6.6.2 Compartment Descriptions

5.a.01 – Command and Control Equipment Room No. 4	
Description:	The Command & Control Equipment Room No. 4 (**CCER4**) is an Electronics – 120 Volts space that houses much of the ship's critical command and control equipment (e.g., command and control equipment processors).

[4] Our interviews with damage control SMEs indicated that damage control reasoning moves from the compartment experiencing damage up to the current 'mission priority' (which corresponds to the abstract and generalized function levels of the AH presented here) and then back down to the compartment level to establish a priority for addressing the damage in that compartment. For example, "there's damage in compartment *x*; the current damage control priority is anti-air warfare, and compartment *x* has radar *y* that is currently needed; therefore the damage in compartment *x* is a priority." Operators seemed to be making links between the physical form and generalized /abstract function levels of the AH, leaving the usual physical function implicit.

5.a.01 – Command and Control Equipment Room No. 4

Location and adjacency:	The CCER 4 is located at $4C_Z$ and is adjacent to the FWD SIS, 57 mm Magazine, 8 Mess, Forward Crew's Washplace and Heads No. 2, and RAS Trunk ($4C_{B0}$). In addition, Diesel Fuel Oil (**DFO**) Tanks 1 and 2 are located below this compartment. Both the port and starboard bulkheads of this compartment are formed by the ship's hull. Its after bulkhead is Watertight Bulkhead 12.

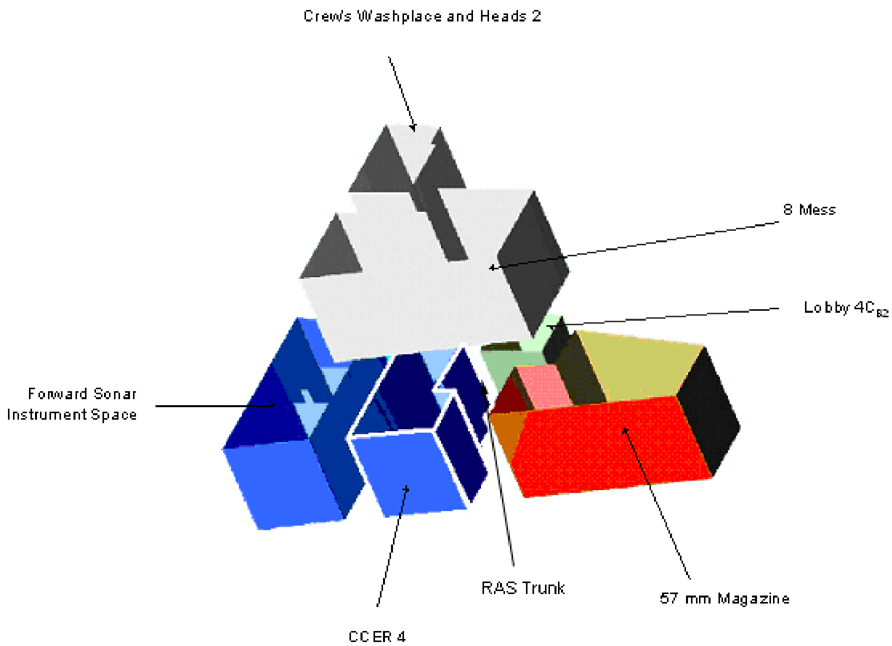

Figure 3-3. Location and adjacency of the CCER4

Access:	This compartment can only be accessed from Lobby $4C_{B2}$, and provides access to no other compartments.
Flooding / drainage:	This compartment is on 4 Deck and is generally partially below the ship's waterline. Primary drainage is provided by eductor suction within the compartment.
Ventilation:	This compartment is in Fire Zone 1. Air is supplied by fan 3E-2 (from AC Plant No. 2) and is exhausted via fan 4C-1 in the adjacent 57 mm Magazine.

5.a.01 – Command and Control Equipment Room No. 4	
Contents:	▪ Acoustic Range Prediction System (**ARPS**) Processor. This processor primarily performs range predictions from inputs including the SQS 510 Hull Mounted Sonar (**HMS**), Canadian Towed Array Sonar System (**CANTASS**), Expendable Bathythermograph / Expendable Sound Velocimeter (**XBT/XSV**), and Echo Sounder. It thereby optimizes the use of underwater sensors for ASW. It is also the primary processor for Shield - Electronic Counter Measure (**ECM**), for all Warfare threats, and the primary Command and Control System (**CCS**) interface with HMS. It also provides backup processing for Link-11 and the Weapon Status Panel. ▪ Assistant Sensor / Weapons Controller (**ASWC**) Processor and DDA. This processor manages the information to and from sensors and weapons for the ASWC Shinpads Display in the Operations Room. The ASWC position is normally manned by the Under-Water Warfare Officer (**UWWO**). ▪ File Manager 2 (**FM2**) Processor. This processor is one of two file manager processors that are absolutely critical to the CCS for all mission types. ▪ File Management DISK 2. Storage for the FM processors and 2049 systems. ▪ 2049 Display. This console is one of three that provide the System Management functions and System Diagnostic tools for CCS. ▪ Navigation 1 (**NAV1**) Processor. NAV1 is one of two navigation processors, and provides the primary processing of the Forward Inertial Navigation System (**FWD INS**) located in the Fwd Gyro Compartment as part of the ship's navigation system. The processed navigation data is critical to the majority of sensors and weapons on the ship. ▪ Command Control Module 2 (**CCM2**) Processor and Node: CCM2 provides the primary processing necessary for the Fwd STIR, Aft STIR, Harpoon, Weapon Veto Panel (**WVP**) in Ops Room, DTSU Switch #2 and CMTU #2, and also holds the Threat Evaluation (**TE**) module. ▪ Uninterruptible Power Supply (**UPS**) 38. Provides a minimum of 5 minutes of backup power to CCM2, CCM2 Node, DISK 2, FM2, NAV1, U2049 and Bus Access Modules (**BAMs**) 1, 5, 9, 13, 17, 21, 25, 29, and 33.
Power considerations:	This compartment uses 120V power and includes UPS 38.
Hazardous materials:	UPS 38 contains NPX-35 Gel Cell Batteries.
System interconnections:	▪ SDB channel 1 terminates at this compartment. ▪ UPS 38 provides 5 minutes of backup power to CCM2, CCM2 Node, NAV 1, FM2, DISK 2, U2049, and BAMs 1, 5, 9, 13, 17, 21, 25, 29, and 33 ▪ Eductor system piping continues through this compartment to provide drainage suction for the FWD SIS. ▪ Grey Water System passes through this compartment.

5.a.02 – Control Systems Workshop	
Description:	The Control Systems Workshop is a Workshop – 120 Volts space that houses Integrated Machinery Control System (**IMCS**) maintenance equipment, computers and manuals.
Location and adjacency:	The Control Systems Workshop is located at $3G_{A4}$ and is adjacent to the Stores Office, Chief and Petty Officers' (**C&PO's**) Lounge Heads, Passageway $3G_{A2}$, and Sickbay. In addition, the After Engine Room (**AER**) is located below this compartment. The port bulkhead of this compartment is formed by the ship's hull. Its forward bulkhead is Watertight Bulkhead 34.

5.a.02 – Control Systems Workshop	
Access:	This compartment can only be accessed from Passageway $3G_{A2}$, and provides access to no other compartments.
Flooding / drainage:	This compartment is on 3 Deck, at 6.2 m above Baseline, and is part of the ship's reserve buoyancy. Primary drainage is provided by deck scuppers in Passageway $3G_{A2}$.
Ventilation:	This compartment is in Fire Zone 4. Air is supplied by fan 2K-3 (from AC Plant No. 1) and has natural exhaust through the passageway.
Contents:	▪ IMCS Maintenance tools ▪ IMCS Maintenance manuals
Power considerations:	This compartment uses 120V power.
Hazardous materials:	None.
System interconnections:	Hot and Cold Fresh Water systems run through this compartment. Located in this compartment, there is one isolation valve for the Hot Fresh Water, and two isolation valves for the Cold Fresh Water.

5.a.03 – Crew's Lounge	
Description:	The Crew's Lounge is a Habitability space that houses a bar and lounge furniture, and also doubles as a Casualty Clearing Station.
Location and adjacency:	The Crew's Lounge is located at $3D_{Z0}$ and is adjacent to the Command Control Equipment Room No. 3, Crew's Cafeteria, Dishwashing Compartment, Passageway $3D_{A2}$, Operations Room, SPS 49 Cooling Equipment Room, Command Control Equipment Room No. 2. In addition, the Dairy Storeroom, Freezer Storeroom and Refrigeration Machinery Space are located below this compartment.
Access:	This compartment can be accessed from Passageway $3D_{A2}$ or from the Crew's Cafeteria, and provides access to no other compartments.
Flooding / drainage:	This compartment is on 3 Deck, at 6.2 m above Baseline, and is part of the ship's reserve buoyancy. Primary drainage is provided by deck scuppers in Passageway $3D_{A2}$.
Ventilation:	This compartment is in Fire Zone 2. Air is supplied by fan 3E-2 (from AC Plant No. 2) and is exhausted via fan 3E-1 in Crew's Cafeteria, Crew's Lounge Head, and Dishwashing Compartment.
Contents:	▪ Lounge furniture ▪ Refrigerators ▪ Ice machine ▪ Drink Dispenser ▪ Washbasin
Power considerations:	This compartment uses 120V power.
Hazardous materials:	None.
System interconnections:	▪ Grey Water System used for the washbasin. ▪ Cold and Hot Fresh Water systems for the washbasin ▪ Black Water System used for the ice machine and the drink dispenser

5.a.04 – Forward Engine Room

5.a.04 – Forward Engine Room	
Description:	The Forward Engine Room (**FER**) is a Machinery space that houses the ship's main engines, main gearbox, and forward part of the shaftlines.
Location and adjacency:	This compartment is located at 6F and is adjacent to the Forward Auxiliary Machinery Room (**FAMR**), AER, C&PO's, Dining Room, C&PO's Servery, Galley A/C Plant, C&PO's Lounge, C&PO's Lounge Head, Tool Crib, Mechanical Workshop, Electrical Workshop, Medical Store, and Passageway $3F_{A2}$. In addition, the DFO Service Tanks No. 1 and 2, Oily Water Collection Tank No. 1, NBC Contamination Collection Tank, Recovered Oil Tank, and Lubricating Oil Tanks No. 1 and 2, are located within this compartment. The port and starboard bulkheads of this compartment are formed by the ship's hull. Its forward bulkhead is Watertight Bulkhead 25.5 and its after bulkhead is Watertight Bulkhead 34.
Access:	This compartment can be accessed from the FER Access Air Lock $3F_{Z2}$, or from the passageway outside the C&PO's Dining Room and Servery. This compartment provides access to the FER Intakes and FER Uptakes, and the Halon Gas Compartment from the FER Intakes.
Flooding / drainage:	This compartment is on 6 Deck, at the lowest point of the ship, and is generally below the ship's waterline. Primary drainage is provided by eductor suction within the compartment, and by the bilge stripping system.
Ventilation:	This compartment is in Fire Zone 3. Air is supplied by fans 6F-1 and 6F-2, and is exhausted via fan 1F-1. NBC Supply Fan 1E-1 also supplies this compartment.
Contents:	▪ Motor Driven Fire Pump 2 ▪ Diesel Driven Fire Pump 1 ▪ Port and Stbd GT's ▪ Main Gearbox ▪ Port and starboard shaftlines ▪ Remote Terminal Units (**RTUs**) 3, 4 and 5 ▪ FER LOP ▪ DFO Tanks 1 and 2 ▪ L/O Tanks 1 and 2 ▪ O/W Collection Tank ▪ NBC Contamination Tank ▪ Recovered Oil Tank ▪ Halon Suppression System - Space ▪ Halon Suppression System - GT Enclosures ▪ AFFF Suppression System - Space ▪ Fuel Oil Service Lines ▪ High Pressure (**HP**) Air System, with 8 flasks for emergency air turbine drives of Main L/O pumps; ▪ HP Air - supply to Clutch Control Cabinet and to air clutches; ▪ Main S/W Circ for Main L/O Cooling; ▪ F/O Booster Pumps, for F/O Service System for GT's and PDE
Power considerations:	This compartment uses 440V power.
Hazardous materials:	This compartment contains DFO, Lube Oil, Freon 22, Trichloroethane, Dykem Red, and B&B 3100. Additionally, this compartment has 8 HP Air flasks.
System interconnections:	▪ The Oil Pollution Abatement System in this compartment has piping going through 3 and 2 Deck above, to the shore connections (port and stbd) for oil discharge on 1 Deck (Upper decks). ▪ Bilge Stripping System serves this compartment and interconnects to the FAMR

5.a.04 – Forward Engine Room

and the AER.

- The Cold Fresh Water System comes to the compartment to serve the Oily Water Separator and Lube Oil Centrifuges, and piping for the C&PO’s Lounge wash basin passes through this compartment.
- The Hot Fresh Water System comes to the compartment to serve the Oily Water Separator, and piping for the C&PO’s Lounge wash basin passes through this compartment.
- The HP Compressed Air System passes through this compartment from the FAMR and the AER. In this compartment the HP Air System serves the Air Clutches and GT breaks, Oily Water Separator, Clutch Control Panel, Forced Lube Oil Pumps and the 8 flasks for emergency air turbine drives of Main L/O pumps.
- The Low Pressure (**LP**) Compressed Air System has one of its air compressor located in this compartment. The LP Air System also interconnects with the FAMR, the AER, and to the LP Air distribution main on 3 Deck above. The LP Air System in this compartment serves the Gas Turbine (**GT**) Water Wash Tank, as well as the Control Air System.
- This compartment contains the Drains System overboard discharges for the following compartment’s deck scuppers and drains; Galley A/C Plant $3F_{A1}$, Passageway $3F_{A2}$, Officer Cabin Flats $2F_{A0}$, Halon Gas Compartment $2F_{B0}$, FER Intakes $1F_{A}$, FER Uptakes 6F, and GT Air Intake Filters $1F_{A}$.
- The Fuel Oil Filling and Transfer System passes through this compartment, and serves DFO Service Tanks No. 1 and 2. It also interconnects with the suction main of the Fuel Oil Service System, and to the emergency cross connections to Fuel Oil Boost Pump discharges.
- The Fuel Oil Service System passes through this compartment, and serves the GTs.
- The Main Sea Water Circulating System in this compartment interconnects to the Auxiliary Sea Water Circulating System from the AER.
- The Main Gearbox, made of the cross-connect gearbox, port gearbox and starboard gearbox, provides interconnection between the engines (i.e. Propulsion Diesel Engine (**PDE**) in the AER and GTs in this compartment) and the Port and Starboard shaftlines.
- The Thrust Blocks in this compartment provide the interconnection between the thrust generated from the propellers through the shaftlines onto the ship’s hull.
- The Forward Local Operating Panel (**LOP**), including the Machinery Controller (**MC**) housed within, and the RTUs 3, 4 and 5, are part of the ship’s IMCS which provide monitoring and control of the main propulsion, ancillaries, as well as auxiliary equipment. The monitoring and control of the machinery can be done automatically, semi-automatically or in manual, and that either remotely from the Machinery Control Room (**MCR**) or locally at the LOP.
- RTU 3 is configured as an Engine Control Module (**ECM**) for the Starboard GT and provides monitoring and/or control of related ancillaries. It must be operable for the Starboard GT to be used.
- RTU 4 is configured as an ECM for the Port GT and provides monitoring and/or control of related ancillaries. It must be operable for the Port GT to be used.
- RTU 5 provides monitoring and/or control of certain propulsion, ancillary and auxiliary equipment located in the FER, including; all gearbox bearing and clutch temperature sensors, thrust block load cells, lube oil air turbines, oil pollution abatement equipment, bilge pump, LP Air compressor, exhaust fan #11 and supply fan #13, Forward Uptake cooling fans #1 and #3, After Uptake cooling fan, and Steam to Port and Starboard LO centrifuge and Fuel Oil Service heating.

5.a.05 – Forward Switchboard	
Description:	The Forward Switchboard (**FWD SWBD**) is an Electrical – 440 Volts space that houses the ship's forward electrical power generation and distribution switchboard.
Location and adjacency:	The FWD SWBD is located at $2E_{Z2}$ and is adjacent to the Confidential Book Vault, Cabin No. 2, Passageway $2E_{A2}$, and NBC Filter Compartment No. 1. In addition, AC Plant No. 2 and Passageway $3E_{A0}$ are located below this compartment. The port bulkhead of this compartment is formed by the ship's hull. Its after bulkhead is Watertight Bulkhead 25.5. Its deckhead is mostly made of the upper decks.
Access:	This compartment can only be accessed from Lobby $4C_{B2}$, and provides access to no other compartments.
Flooding / drainage:	This compartment is on 2 Deck, at 8.65 m above Baseline, and is part of the ship's reserve buoyancy. Primary drainage is provided by deck scuppers in Passageway $2E_{A2}$, which discharge overboard in the FAMR.
Ventilation:	This compartment is in Fire Zone 2. Air is supplied by fan 3E-2 (from AC Plant No. 2) and is exhausted via fan 3E-1 from Wardroom Locker and Wardroom Servery.
Contents:	Forward Switchboard. This is one of the two Power Generation & Distribution System switchboards. It manages the ship's electrical power generation and distribution.
Power considerations:	This compartment uses 440 Volts.
Hazardous materials:	UPS Batteries.
System interconnections:	▪ SDB channel 3 passes through this compartment. ▪ LP Compressed Air System has a low point drainage connection in this compartment. ▪ Port side deck filling line for the Fuel Oil Filling and Transfer System comes in through deckhead and exits into passageway $2E_{A2}$. Additionally, the isolating valve is located in this compartment. ▪ Pre-Wet System passes through this compartment.

5.a.06 – General Store No. 2	
Description:	General Store No. 2 is a Store type space used to store various spare parts for the ship's equipment.
Location and adjacency:	This compartment is located at $4K_Z$ and is adjacent to the JP5 Pump Room, Fire Control Equipment Room No. 3, Ship's Laundry, Entertainment Broadcast Room, General Store No. 3, Emergency Fire Pump Room, 14 Mess, 15 Mess, 16 Mess, Passageway $3K_{A2}$, and Crew's Head No. 3. In addition, JP5 Tanks No. 1 and 2, and DFO Tanks 10 and 11, are located below this compartment. The port and starboard bulkheads of this compartment are formed by the ship's hull. Its forward bulkhead is Watertight Bulkhead 47.5 and its after bulkhead is Watertight Bulkhead 52.5.
Access:	This compartment can be accessed from Lobby $4K_{A2}$, and provides access to no other compartments.
Flooding / drainage:	This compartment is on 4 Deck, at 3.75 m above Baseline, and is generally partially below the ship's waterline. Primary drainage is provided by eductor suction within the compartment.
Ventilation:	This compartment is in Fire Zone 5. Air is supplied by fan 2K-3 (from AC Plant No. 1) and is exhausted via fan 01-J-2 from JP5 Pump Room.
Contents:	This compartment contains primarily spare parts for the ship's equipment.

5.a.06 – General Store No. 2	
Power considerations:	This compartment uses 120V power.
Hazardous materials:	None.
System interconnections:	▪ Grey Water System passes through this compartment. ▪ Bilge Stripping System passes through this compartment.

5.a.07 – Paint Store	
Description:	The Paint Store is a Store type space, used for the storage of paints and solvents.
Location and adjacency:	This compartment is located at $2A_A$ and is adjacent to the Paint Locker, Cleaning Gear Store No. 1, General Store No. 1, and Rope Store & Bosun's Workshop. In addition, there is a void space below this compartment. Since this compartment is in the forward peak of the ship, all bulkheads except the after one are formed by the ship's hull.
Access:	This compartment can be accessed from the Paint Locker ($2A_{Z1}$), and provides access to no other compartments.
Flooding / drainage:	This compartment is on 2 Deck, at 8.65 m above Baseline, and is part of the ship's reserve buoyancy. Primary drainage is provided by deck scuppers that drain to the void space below, and then through eductor system suction in that void space.
Ventilation:	This compartment is in Fire Zone 1. Air is supplied naturally, and is exhausted via fan 2B-1 (in Anchor Capstan Compartment $2B_A$).
Contents:	This compartment contains paints and solvents.
Power considerations:	This compartment uses 120V power.
Hazardous materials:	This compartment contains paints and solvents.
System interconnections:	None.

5.a.08 – Port Torpedo Magazine	
Description:	The Port Torpedo Magazine is a Magazine space that is used to both store and launch the MK 46 Torpedoes, which are high speed acoustic homing torpedoes used to seek and destroy subsurface targets.
Location and adjacency:	This compartment is located at $1H_{A2}$ and is adjacent to the Sonobuoy Store No. 1, Flight Deck Control Room & Damage Control Section Base No. 3, Hangar, Port Hangar Lobby, CSE Office, Marine Systems Engineering Office, and Air Detachment Room. In addition, the Smoke Marker Locker, SUS Locker, Pyrotechnics Locker, Life Rafts and Lifejackets are stored above this compartment on the upper decks, at 01 Deck, where a .50 Calibre Machine Gun is also located. The port bulkhead of this compartment is formed by the ship's superstructure shell. Its forward bulkhead is Watertight Bulkhead 43 and its after bulkhead is Watertight Bulkhead 47.5.
Access:	This compartment can be accessed from the Port Hangar Lobby ($1J_{A2}$) or from the Hangar ($1J\text{-}_{A0}$), and provides access to no other compartments.
Flooding / drainage:	This compartment is on 1 Deck, at 11.4 m above Baseline, and is part of the ship's reserve buoyancy. Primary drainage is provided by the scuppers and drains to overboard discharge.

5.a.08 – Port Torpedo Magazine	
Ventilation:	This compartment is in Fire Zone 4. Air is supplied by fan 1H-2 within this compartment, and is exhausted naturally and via a pressure relief valve.
Contents:	This compartment contains a torpedo launcher and MK 46 Torpedoes, which are high speed acoustic homing torpedoes used to seek and destroy subsurface targets, and launched from either this compartment of from the Helicopter. The MK 46 Torpedoes are a means to Effectors and Helicopter Support.
Power considerations:	This compartment uses 120V power.
Hazardous materials:	This compartment contains twelve MK 46 Torpedoes that are explosives, and also contain Otto Fuel II.
System interconnections:	▪ High Pressure Air System comes in to supply a compressed air flask, for the torpedo launcher. ▪ Scuppers and Drains System to overboard discharge on 4 Deck below in the Loan Clothing Store ($4J_{A4}$).

5.a.09 – Radar Room No. 2	
Description:	The Radar Room No. 2 is an Electronics – 440 Volts space that primarily houses the radar equipment for the SPS 49 Long Range Radar, and other electronics in support to sensors.
Location and adjacency:	The Radar Room No. 2 is located at $2D_{Z0}$ and is adjacent to the SPS 49 Cooling Equipment Room, CCER 2, Female Officer's Washplace & Sea Head, Wardroom, Passageway $2D_{Z2}$ (Ops Room Flats), Lobby $1D_{Z0}$, CO's Dining Room, CO's & SO's Washroom, SO's Cabin, and Crew's Cafeteria. The starboard bulkhead of this compartment is formed by the ship's hull. The after bulkhead is Watertight Bulkhead 20.5.

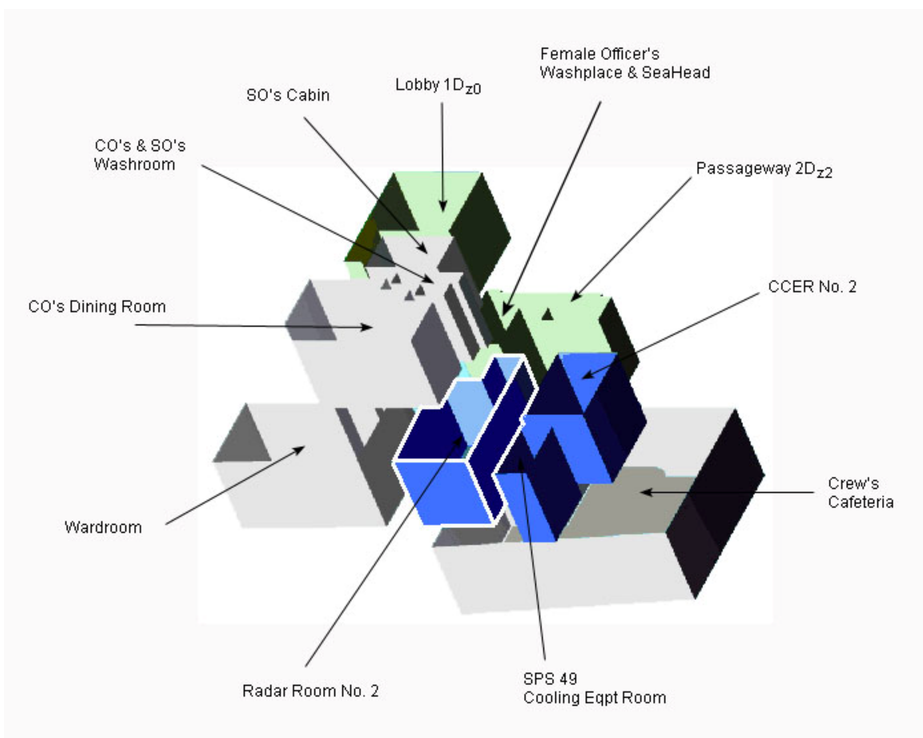

Figure 3-4. Location and adjacency of Radar Room No. 2

5.a.09 – Radar Room No. 2	
Access:	This compartment can only be accessed from the Ops Room Flats (Passageway $2D_{Z2}$), and provides the only access to the SPS 49 Cooling Equipment Room.
Flooding / drainage:	This compartment is on 2 Deck, at 8.65 m above Baseline, and is part of the ship's reserve buoyancy. Primary drainage is provided by deck scuppers in Ops Room Flats (Passageway $2D_{Z2}$).
Ventilation:	This compartment is in Fire Zone 2. Air is supplied by fan 3E-2 (from AC Plant No. 2) and is exhausted via fan 3E-1 (from Wardroom and Female Officer's Washplace Sea Head).
Contents:	▪ SPS-49. The SPS-49 is a Long Range Surveillance Radar. It is a 2-D Above Air Warfare (**AAW**) Air Tracking Radar, which generally only serves for that purpose. ▪ Radar Distribution Unit (**RDU**). The RDU processes all radar inputs, including the SPS-49, SG-150, Kelvin Hughes Navigation Radar, and the MK XII IFF, and distributes to all displays. ▪ Tactical Air Navigation (**TACAN**). The TACAN transmits ship range and bearing information for helicopter operations, for air safety purposes. It is not normally used in under any Warfare threat environment. ▪ MK XII IFF. In this compartment, this consists of the SPS-49 IFF transponder and interrogator, which is used for Identification Friend or Foe for air operation only.
Power considerations:	This compartment uses 440 Volts power.
Hazardous materials:	None.
System interconnections:	▪ SDB channel 3 passes through this compartment, from Passageway $2D_{Z2}$ to CCER 2. ▪ The LP Compressed Air System supplies a Dehydrator in this compartment. ▪ The Scuppers and Drains System for the deck scuppers in FCER 1 ($01D_{C0}$) and Lobby $01D_{Z2}$ passes through this compartment.

5.a.10 – Ship's Laundry	
Description:	The Ship's Laundry is a Habitability space used primarily for washing the ship's laundry.

5.a.10 – Ship's Laundry

Location and adjacency: This compartment is located at $4J_{A1}$ and is adjacent to the Gyro Room No. 2, Fire Control Equipment Room No. 3, Shelter Station No. 2, JP5 Pump Room, General Store No. 2, After Auxiliary Machinery Room, PO's Washplace & Heads No. 2, 9 Mess and 11 Mess. In addition, Fresh Water Tank No. 1 and the Sewage Treatment Plant are located below this compartment, as well as the cofferdam that runs between Fresh Water Tank No. 1 and the Treated Water Tank. The starboard bulkhead of this compartment is formed by the ship's hull. Its forward bulkhead is Watertight Bulkhead 43 and its after bulkhead is Watertight Bulkhead 47.5.

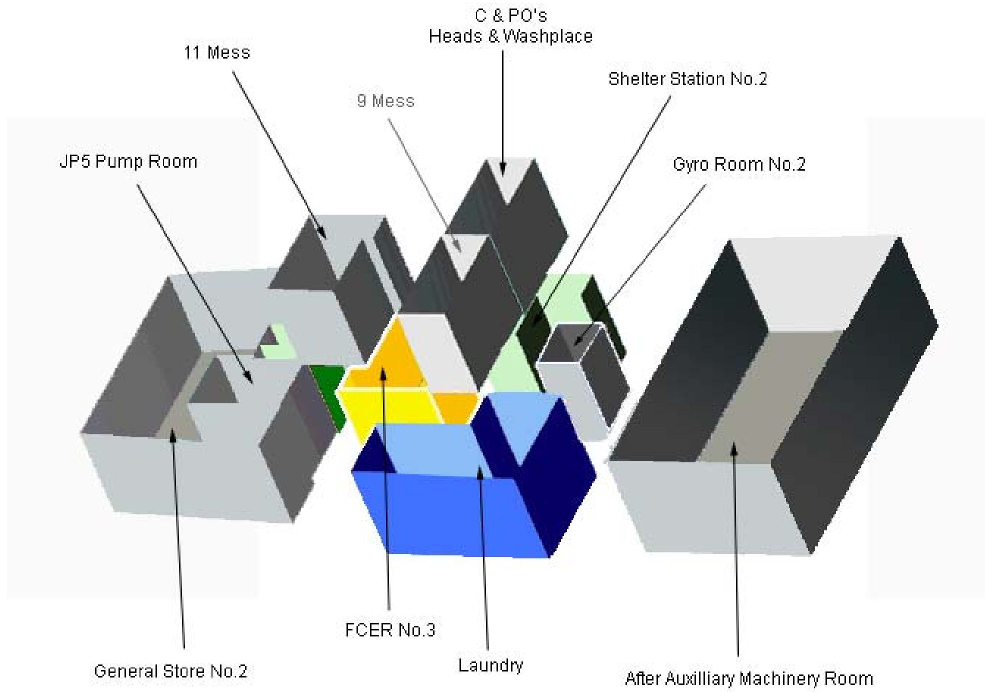

Figure 3-5. Location and adjacency of the Ship's Laundry

Access:	This compartment can be accessed from Shelter Station No. 2 ($4J_{A2}$), and provides access to no other compartments.
Flooding / drainage:	This compartment is on 4 Deck, at 3.75 m above Baseline, and is generally partially below the ship's waterline. Primary drainage is provided by eductor suction within the compartment. In addition, deck drains drain to the Grey Water system.
Ventilation:	This compartment is in Fire Zone 5. Air is supplied by fan 2K-3 (from AC Plant No. 1) and is exhausted via fan 2K-2 (in AC Plant No. 1).
Contents:	This compartment contains commercial laundry equipment and other sundry items.
Power considerations:	This compartment uses 120V power.
Hazardous materials:	This compartment may contain detergents and bleach.

5.a.10 – Ship's Laundry	
System interconnections:	▪ SDB Channel 2 passes through this compartment from 9 Mess to Fire Control Equipment Room No. 3. ▪ This compartment contains the Drains System overboard discharges for the following compartment's deck scuppers and drains; Lobby $2J_{A1}$, Passageway $3J_{A2}$ (outside 9 Mess), Hangar, Helo Ready-Use Lube Locker and Lobby $1J_{A1}$. ▪ LP Compressed Air System comes in to supply laundry equipment, and continues through to the JP5 Pump Room. ▪ Hot Fresh Water System comes in to supply laundry equipment. ▪ Cold Fresh Water System runs to and from Fresh Water Tank No. 1 and Shelter Station No. 2 ($4J_{A2}$) through this compartment, and supplies laundry equipment. ▪ Environment Pollution Control systems, including Grey Water, Black Water and Bilge Stripping systems, come through this compartment, while the Grey Water System also serves this compartment's laundry equipment and drainage system.

5.a.11 – Shipwright's Workshop	
Description:	The Shipwright's Workshop (or Hull Tech Workshop) is a Workshop space that houses various woodworking and metal shop tooling and equipment, as well as Argon and Oxy-Acetylene welding equipment.
Location and adjacency:	The Shipwright's Workshop is located at $2L_{Z4}$ and is adjacent to the Firefighting Equipment & Damage Control Store, NBC Filter Compartment No. 4, Damage Control Lobby $2L_{A0}$, and Flight Deck. In addition, 18 Mess is located below this compartment. The port bulkhead of this compartment is formed by the ship's hull. Its after bulkhead is Watertight Bulkhead 58.
Access:	This compartment can only be accessed from Damage Control Lobby $2L_{A0}$, and provides access to no other compartments.
Flooding / drainage:	This compartment is on 2 Deck, at 8.65 m above Baseline, and is part of the ship's reserve buoyancy. Primary drainage is provided by deck scuppers in Damage Control Lobby $2L_{A0}$.
Ventilation:	This compartment is in Fire Zone 5. Air is supplied by fan 2K-3 (from AC Plant No. 1) and is exhausted via fan 2L-1 in this compartment.
Contents:	▪ Argon welding equipment ▪ Oxy-Acetylene welding equipment ▪ Various metal and woodworking tooling and equipment (e.g. quench tank, band saw, drill press, grinder)
Power considerations:	This compartment uses 120V power.
Hazardous materials:	This compartment contains Argon, Oxygen and Acetylene bottles.
System interconnections:	LP Compressed Air System terminates in this compartment.

5.a.12 – Steering Gear Compartment	
Description:	The Steering Gear Compartment is a Machinery space that houses the steering gear.
Location and adjacency:	The Steering Gear Compartment is located at $3M_{A0}$ and is adjacent to the Rope Store, Lobby $3M_{A2}$, 19 Mess, Firefighting Shelter Lobby $2M_{A0}$, Undress part of Cleaning Station No. 2, Towed Array Equipment Room, and Deck Store No. 3. In addition, a void space is located below this compartment. Its forward bulkhead is Watertight Bulkhead 58.

5.a.12 – Steering Gear Compartment	
Access:	This compartment can only be accessed from Lobby $3M_{A2}$, and provides access to no other compartments.
Flooding / drainage:	This compartment is on 3 Deck, approximately 5.2 m above Baseline (3 Deck at the stern is approximately 1 m below 3 Deck at midships), and is part of the ship's reserve buoyancy. Primary drainage is provided by eductor suction within the compartment, and by the bilge stripping system.
Ventilation:	This compartment is Aft of Fire Zone 5. Air is supplied by fan 2K-3 (from AC Plant No. 1) and is exhausted via fan 2K-2 in Rope Store.
Contents:	▪ Rotary Vane Steering Gear System. This system operates a single spade type rudder. It consists of two independent identical pumpsets, one rotary vane actuator, a rudder self-centering device, and emergency hydraulic hand pump. Hydraulic oil is supplied from two 530 litre reservoir tanks situated in this compartment. Each fixed displacement pump is driven by a constant speed, electric motor and is fitted with a servo controlled, four-way flow valve which directs hydraulic oil flow. Local electrical control of the servo valve to accommodate interruption or failure of the steering control system is installed. ▪ The Steering Gear System also includes a manually operated automatic rudder centering device consisting of a 273 litre accumulator system, complete with charging pump and electric motor. ▪ An emergency helm pump is also fitted in this compartment. It provides manual emergency steering capability.
Power considerations:	This compartment uses 440V power.
Hazardous materials:	Hydraulic Oil.
System interconnections:	Steering Gear System Control Signals

SECTION FOUR: DISCUSSION AND CONCLUSIONS

4.1 GENERAL

This section includes a discussion following up on some of the AH modelling issues that were experienced during the conduct of this work as well as a brief conclusion.

4.2 STAKEHOLDERS AND OBJECT WORLDS IN MILITARY SYSTEMS

As outlined in Section 3.3.3, understanding that damage control is not a work domain in itself, but is instead an object world within the work domain of ship systems was an important insight that helped us to properly define the work domain that damage control acts on, and so to perform a correct WDA for damage control. In light of the completed AH, it is now possible to perform a more detailed analysis of these object worlds and of their overlaps and the places in which they diverge from one another.

Common Navy doctrine can help in understanding the key overlap of these object worlds. According to the Navy's current strategic plan, the core Canadian Naval competencies are summed up by the "basic Naval concept[s]" of "to float," "to move," and "to fight" (Canadian Department of National Defence, 2001, pp. 117-118). These competencies are echoed on the first page of the damage control manual for Halifax-class ships: "Damage Control … assist[s] in achieving the ultimate aim of the ship: TO FLOAT, TO MOVE, AND TO FIGHT" (Department of National Defence, 2003a, p. 1, emphasis in the original). The Naval Engineering Manual, which is studied by both MSEs and CSEs, includes at least two references of the same nature (Canadian Department of National Defence, 2003b). Further, in conversations with officers from all object worlds these concepts were frequently referred to. "To float, to move, and to fight" – or, as expressed in the AH, the system-level functional purposes of *Stability*, *Manoeuvrability*, and *Mission Effectiveness* – are clear high level objectives for each object world. As shown in Table 4-1, Burns, *et al.* (2005) found a similar set of system-level functional purposes for the object world of Command and Control.[5]

[5] Though not germane to this discussion, it is also notable that a secondary publication of Burns et al.'s (2005) WDA of Naval Command and Control (Burns, Bisantz, and Roth, 2004) also included one additional system-level functional purpose, *Meet naval values: Goals for effectiveness, economics, force balance, adherence to law* that is similar in content but broader in scope than our system-level functional purposes of *Personnel safety*, *Economic stewardship*, and *Environmental protection*.

Naval Doctrine	AH of ship functions from the perspective of the damage control object world	AH of ship functions from the perspective of the Command and Control object world (Burns, et al., 2005)
To float	Stability	Maintain own survival
To move	Manoeuvrability	Move from A to B
To fight	Mission Effectiveness	Maximize sea control Maximize information gathering

Table 4-1. Comparison between system-level functional purposes as outlined in Naval doctrine, the current study, and as per Burns *et al.*'s (2005) WDA of Naval Command and Control.

This evidence makes a strong case that the fundamental overlap between these object worlds is at the level of system functional purposes.

Though the same strong evidence does not exist for overlaps at the subsystem levels of abstract function and generalized function, it is reasonable to think that the object worlds of CSE and MSE would share in the concerns at this level. For instance, CSE, MSE and damage control have a shared concern for *Power generation*; MSE, Command and Control, and damage control have a shared concern for *Propulsion* and *Steering*; and CSE, Command and Control, and damage control have a shared concern for the *Ability to sense environment* and *Ability to affect environment*.

The unique purviews of each object world are then expressed at the level of component physical functions and physical forms. For example, the object worlds of damage control and MSE are each concerned with the ship's engines, but damage control is concerned with making sure the engine spaces are free from floods, fires, and structural damage so that the engines can operate, while MSE is concerned with ensuring that the engines themselves are operating properly.

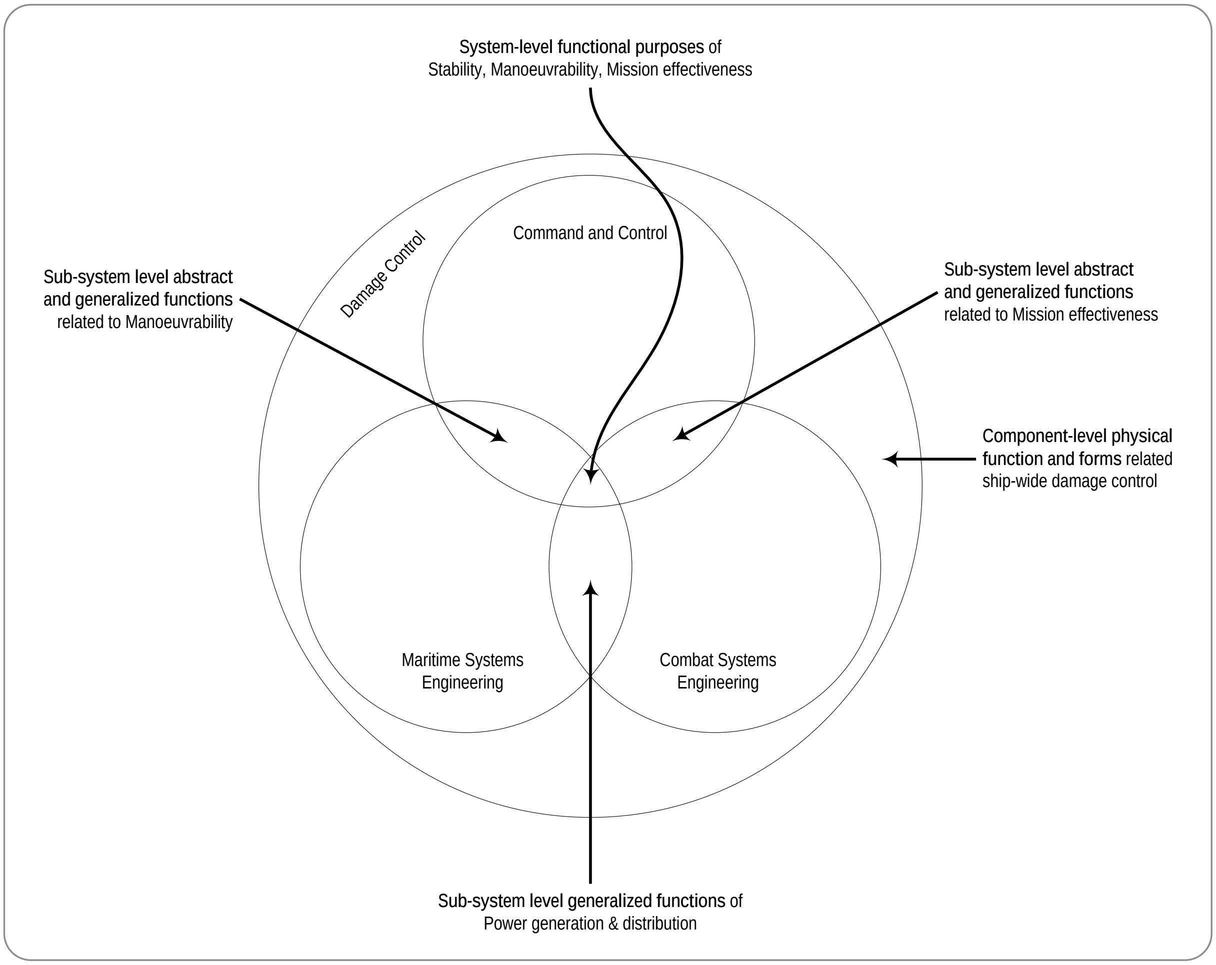

Figure 4-1. Object world overlaps

The high-level overlap and increasing lower-level disconnect between these object worlds is notable because according to a review by Naikar, *et al.* (2005), while overlaps at multiple levels of abstraction are possible, so far the WDA literature only includes overlaps at the single level of physical forms. In the systems in which object-world overlaps were discovered (e.g., engineering design, network management, an elevator firm, and health care), the different stakeholders in the system were not unified through a strict organizational hierarchy. The Navy, on the other hand, has a strict organizational hierarchy specifically designed for the advancement of a singular set of goals. In hindsight, that the various stakeholder object worlds are most unified at the system-level of functional purposes is not surprising: military organizations have evolved over time specifically for this purpose. That the differences in object worlds express themselves increasingly at lower levels of abstraction implies that the various stakeholders are working within their individual object worlds to the advancement of a set of common goals. This is in contrast to many of the prior analyses in which the various stakeholders were working on a common set of physical artefacts toward the advancement of compatible but potentially divergent goals (e.g., patients and doctors in health care; the public and architects with respect to an elevator firm; company management and third-party suppliers in network management; or ergonomics designers and implementers in an engineering design problem).

4.3 CONCLUSIONS AND FUTURE WORK

This report has described the development of a functional, means-end model of damage control using an AH representation. The overall effort was well-grounded in the literature of the research and practice communities of optimized crewing and damage control, and on thorough domain analysis of damage control that was conducted via a literature review of CPF documentation and extensive SME interviews. The model that was produced was validated through three separate reviews, two with SMEs and one with the project SA. Finally, since the model will be referred to frequently in the remaining phases of this project, it has been documented thoroughly in a way that captures the important modelling decisions and rationale for future reference. In the opinion of the project team, the work presented in this volume is a strong basis for the follow-on phases of this project.

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ANNEX A
GLOSSARY OF TERMS AND ACRONYMS

ANNEX A: GLOSSARY OF TERMS AND ACRONYMS

AAW.	Above Air Warfare
AER.	After Engine Room
AFFF.	(pronounced ‘A-triple-F’) Aqueous Film Forming Foam
AH.	Abstraction Hierarchy
ARPS.	Acoustic Range Prediction System
ASW.	Anti-Submarine Warfare
ASWC.	Assistant Sensor / Weapons Controller
BAM.	Bus Access Module
C&PO’s.	Chief and Petty Officers’
CANTASS.	Canadian Towed Array Sonar System
CBM.	Condition-Based Maintenance
CCER4.	Command and Control Equipment Room No. 4
CCM2	Command Control Module 2
CCS	Command and Control System
CDM	Critical Decision Method
Cdr	Commander
CFNES	Canadian Forces Naval Engineering School
CO	Commanding Officer
COTS	Commercial-Off-the-Shelf
CPF	(Halifax Class) Coastal Patrol Frigate
CPO	Chief Petty Officer
CSE	Combat Systems Engineering
CVF	Future Aircraft Carrier
DC-ARM	Damage Control – Automation for Reduced Manning
DCO	Damage Control Officer
DFO	Diesel Fuel Oil
DRDC-T	Defence Research and Development Canada – Toronto
ECM	Engine Control Module, Electronic Counter Measure
ERT	Emergency Response Team
FAMR	Forward Auxiliary Machinery Room
FER	Forward Engine Room
FM2	File Manager 2
FWD INS	Forward Inertial Navigation System
FWD SWBD	Forward Switchboard
GAO	General Accounting Office
GT	Gas Turbine
HFE	Human Factors Engineering
HMS	Hull Mounted Sonar
HP	High Pressure
HSI	Human Systems Integration
IMCS	Integrated Machinery Control System
IPME	Integrated Performance Modelling Environment
LAN	Local Area Network
LCdr	Lieutenant Commander
LOP	Local Operating Panel
LP	Low Pressure

MCR	Machinery Control Room
MSE	Maritime Systems Engineering
NAV1	Navigation 1
NBCD	Nuclear, Biological, and Chemical Defence
PDE	Propulsion Diesel Engine
PG&D	Power Generation & Distribution
RDU	Radar Distribution Unit
RTU	Remote Terminal Unit
SA	Scientific Authority
SCSC	Single-Class Surface Combatant
SME	Subject Matter Expert
SSOs	Ship Standing Orders
TACAN	Tactical Air Navigation
TE	Threat Evaluation
UPS	Uninterruptible Power Supply
UWWO	Under-Water Warfare Officer
WDA	Work Domain Analysis
WLC	Whole-life Cost
WVP	Weapon Veto Panel
XBT/XSV	Expendable Bathythermograph / Expendable Sound Velocimeter

ANNEX B
AH QUESTIONNAIRE (FROM NAIKAR, ET AL., 2005)

ANNEX B: AH QUESTIONNAIRE (FROM NAIKAR, ET AL., 2005)

Abstraction Level[6]	**Prompts**	**Keywords**
Functional purposes	Purposes: ▪ For what reasons does the work system exist? ▪ What are the highest-level objectives or ultimate purposes of the work system? ▪ What services does the work system provide to the environment? ▪ What needs of the environment does the work system satisfy? ▪ What role does the work system play in the environment? ▪ What has the work system been designed to achieve? ▪ What are the values of the people in the work system? External Constraints: ▪ What kinds of constraints does the environment impose on the work system? ▪ What values does the environment impose on the work system? ▪ What laws and regulations does the environment impose on the work system? ▪ What societal laws and conventions does the environment impose on the work system?	Purposes: reasons, goals, objectives, aims, intentions, mission, ambitions, plans, services, products, roles, targets, aspirations, desires, motives, values, beliefs, views, rationale, philosophy, policies, norms, conventions, attitudes, customs, ethics, morals, principles. External constraints: laws, regulations, guidance, standards, directives, requirements, rules, limits, public opinion, policies, values, beliefs, views, rationale, philosophy, norms, conventions, attitudes, customs, ethics, morals, principles.
Values and priority measures	▪ What criteria can be used to judge whether the work system is achieving its purposes? ▪ What criteria can be used to judge whether the work system is satisfying its external constraints? ▪ What criteria can be used to compare the results or effects of the purpose-related functions on the functional purposes? What are the performance requirements of various functions in the work system? How is the performance of various functions in the work system measured or evaluated and compared? ▪ What criteria can be used to assign priorities to the purpose-related functions? ▪ What are the priorities of the work system? How are priorities assigned to the various functions in the work system? ▪ What criteria can be used to allocate	Criteria, measures, benchmarks, tests, assessments, appraisals, calculations, evaluations, estimations, judgements, scales, yardsticks, budgets, schedules, outcomes, results, targets, figures, limits. Measures of: effectiveness, efficiency, reliability, risk, resources, time, quality, quantity, probability, economy, consistency, frequency, success. Values: laws, regulations, guidance, standards, directives, requirements, rules, limits, public opinion, policies, values, beliefs, views, rationale, philosophy, norms, conventions, attitudes, customs, ethics, morals, principles.

[6] Naikar et al. (2005) used different names for the various levels of abstraction, but their labels do correspond well to the levels of Functional purpose, Abstract function, Generalized function, Physical function, and Physical form as used in this report.

Abstraction Level[6]	Prompts	Keywords
	resources (e.g., material, energy, information, people, money) to the purpose-related functions? What resources are allocated to the various functions of the work system? How are resources allocated to the various functions of the work system?	
Purpose-related functions	▪ What functions are required to achieve the purposes of the work system? ▪ What functions are required to satisfy the external constraints on the work system? ▪ What functions are performed in the work system? ▪ What are the functions of individuals, teams, and departments in the work system? ▪ What functions are performed with the physical resources in the work system? ▪ What functions coordinate the use of the physical resources in the work system?	Functions, roles, responsibilities, purposes, tasks, jobs, duties, occupations, positions, activities, operations.
Object-related processes	▪ What can the physical objects in the work system do or afford? ▪ What processes are the physical objects in the work system used for? ▪ What are the functional capabilities and limitations of physical objects in the work system? ▪ What physical, mechanical, electrical, or chemical processes are afforded by the ▪ physical objects in the work system? ▪ What functionality is required in the work system to enable the purpose-related functions?	Processes, functions, purposes, utility, role, uses, applications, functionality, characteristics, capabilities, limitations, capacity, physical processes, mechanical processes, electrical processes, chemical processes.
Physical objects	▪ What are the physical objects or physical resources in the work system – both man-made and natural? ▪ What physical objects or physical resources are necessary to enable the processes and functions of the work system? ▪ What is the inventory (e.g., names, number, types) of physical objects or physical resources in the work system? ▪ What are the material characteristics (e.g., external form including shape, dimensions, colour; internal configuration; material composition) of physical objects or physical resources in the work system? ▪ What is the topography or organisation (e.g., layout or location of physical objects in relation to each other) of physical objects or physical resources in the work system?	Man-made and natural objects: tools, equipment, devices, apparatus, machinery, items, instruments, accessories, appliances, implements, technology, supplies, kit, gear, buildings, facilities, premises, infrastructure, fixtures, fittings, assets, resources, staff, people, personnel, terrain, land, meteorological features. Inventory: names of physical objects, number, quantities, brands, models, types. Material characteristics: appearance, shape, dimensions, colour, attributes, configuration, arrangement, layout, structure, construction, make up, design. Topography: organisation, location, layout, spacing, placing, positions,

Abstraction Level[6]	Prompts	Keywords
		orientations, ordering, arrangement.

Table B-1. Comparison between system-level functional purposes as outlined in Naval doctrine, the current study, and as per Burns *et al.*'s (2005) WDA of Naval Command and Control.

ANNEX C
NOTES FROM SME INTERVIEWS

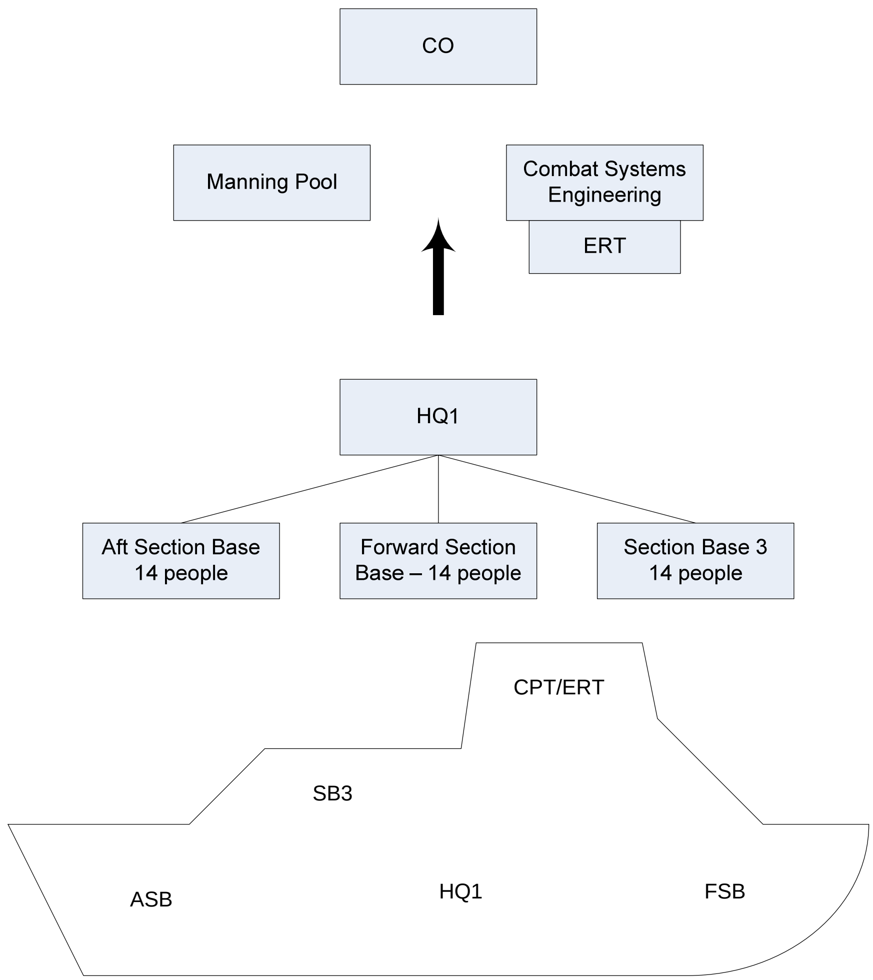
ANNEX C: NOTES FROM SME INTERVIEWS

The following notes are transcribed from the SME interviews carried out on January 18 and 25, 2006.

January 18 – Visit with LCdrs Olivier and Kennedy

Attendees: LCdr Jacques Olivier; LCdr Nigel Kennedy; Luc Cournoyer; Gerard Torenvliet

- Damage Control officer reads everything off of an incident board. This board is marked up using grease markers, and is used to organize information about any situation on the ship.
- It is important to distinguish between two different situations: Peacetime (in which sensors raise an alarm, which brings the ship to damage control stations and mobilizes the DC team; a rapid response team goes directly to the location to try and confine or extinguish the fire) and battle stations (in which there is no rapid response team, but instead the fire is prioritized against other battle priorities and fought within its place in the priority queue). The example that was given here is that in peacetime people will run to deal even with a fire in the potato locker. In contrast, when at battle stations, they might just contain that fire and ignore it.



- Damage Control Organization is shown in the figure above. HQ1 is the central station that manages the damage control effort; they work to ensure that all teams in the various section bases are fighting the highest priority fires. They have the incident board.
- The incident board is populated with information by a plotter. One of the main early sources of information is from heat and smoke sensors located in each of the compartments (over 1000 of them), but the view these sensors give is aggregated so that operators can only localize fires to zones on the ship. In a sense, sensors are only useful for random fires; fires caused by damage spread smoke everywhere so many alarms go off. In this case, survey teams (2 per section) are directed to go out and localize the damage.
- The CO ensures that the DCO gets the right priorities to be able to address the damage in the way that will best suit the ship's mission. So there seems to be a hierarchy of purposes – the ship's purposes order the damage control effort at the first level, and the more local purposes of the DCO order the damage control effort at the second level. The ship's purposes vis a vis damage control change by mission type – different strategies are used for ASW vs. AAW and AWW.
- The damage control organization also includes combat systems engineers; they are responsible for going out and fixing equipment so that it functions again after damage. CSEs have an emergency response team whose chief responsibility is to go out and make necessary repairs (like re-routing power cables).
- The manning pool is a source of unspecialized people who will be available for helping to control the damage (everyone knows how to fight fires). The manning pool is a part of the supply depot.
- HQ1's responsibility is to provide the CO with filtered information – "Deck 1 clear, Deck 2 clear, Deck 3 has 3 fires". The filtering is sensitive to the DCOs understanding of the ship's purposes at this moment, so that any information that is specially significant to the ship's overall mission will be delivered to the CO.
- There is a location backup for HQ1 that the five-person team from HQ1 can move to if there are any problems in their normal location. In addition, there is a second HQ (HQ2) near the ASB that is a backup.
- HQ1 is co-located with the Machinery Control Room; this location helps the DCO to have an idea of how well the ship's propulsion is working.
- The DCO also has a compartment risk profile that helps the DCO to understand the effects of damage on various compartments so that they will fight the right fires.
- ACTION: Ask LCdr Heimpel if he has this document for us.
- Before fighting a fire with water it is important to isolate power. This can be a challenge because power cannot be isolated precisely by compartment but by zone; sometimes power can't be shut down to resolve a fire because that power is needed, e.g., for one of the ship's guns. Thus it is important to co-ordinate power shutdown with the customers of that power (or rather, with the other purposes of the ship).
- A pumping and flooding team are responsible for removing water from the ship. If flooding is bad in a compartment, they may opt to seal the compartment and as a part of this work they often also have to shore up the surrounding structure. A compartment might also be sealed to help maintain the stability of the boat. Water sloshing around in a compartment affects stability much more than a full compartment that is equalized with the outside environment.

- Some compartments – those most critical to the ship's purposes – have fixed fire fighting equipment; generally HALON dispensers.
- In the view of the SMEs at this meeting, ship repair is a part of damage control.
- Typical battle scenario: after a torpedo hits the ship, a survey team goes to find and localize the damage.
- All damage control priorities are published by HQ1, but they are set by the DCO in cooperation with the CO.
- The ship has 1000 sensors, but they are aggregated into single lights on the incident board – 1000 sensors down to 30 or 40 lights, that represent zones by types of damage.
- A rocket causes smoke to go everywhere; consequently, the sensors are most useful in harbour fire situations.
- The state of technology in the current damage control room means that too much effort is spent coordinating the overall picture. A plotter controls the incident board; a communications person sends and receives messages to the CO and between the various bases; one person manages the damage control system; and there is another position (5 in total) in HQ1.
- There are three types of scenarios – Action scenario at sea (when you still have to fight the ship); Peacetime emergency at sea (you're not trying to fight the ship, so you have everyone available); Harbour incident with a reduced crew. Action scenarios are the most complex and most important for testing the promise of optimized crewing; they should probably be used for this effort.
- ACTION: Also see if LCdr Heimpel has information about the damage control organization; the people on the various teams.
- There are three different fire types – carbonaceous fires that are extinguished by water; oil fires that are extinguished by Aqueous Film Forming Foam (AFFF); and CO2/HALON that are used for all types of fires. HALON especially is effective, but expensive, and is currently a restricted substance (it depletes the ozone layer).
- Rooms with electronics tend to have automatic fire suppression systems (or, fitted fire suppression systems).
- The main problems from the point of view of these operators are information communication and the loss of sensors.
- Stability is an issue – they currently use a program to keep a daily inventory of the weight and balance of the ship, so that during a damage control situation they can make better judgments for when to fully flood a compartment, etc. The overall buoyancy of the ship is also an issue; you can only let flooding happen if there is buoyancy left over.
- There are also structural issues at play. DCOs have to keep track of the structure of the ship vis a vis any damage that has been sustained.
- There are physical balances at play here but also functional balances – compartments can only be sacrificed if they are not key to the ship's current mission.
- Ships generally have drain down valves to make sure that water goes to the bottom of the ship.
- Another issue is Nuclear Biological Chemical Defense (NBCD). The first phase of this type of defense is called pre-wet, and this basically puts a cloud of water around the ship to intercept any gaseous agents. When they have to lock down, people get in the ship into specially sealed off areas called 'citadels' that are put under positive air pressure. Especially

when people are in these citadels the total approach to damage control can change because another purpose has been layered in – ensure the important parts of the ship are not contaminated.

- The Falklands case is important; it changed the approach to damage control.
- Things to read: Shipboard Damage Control 1 of 4 and HFX Class DC Information Book

January 24 – Visit with Cdrs Lavallée and Gagnon

Attendees: Cdr Jean Lavallée (JL); Cdr Gagnon (G); Dave McKay (DM); Gerard Torenvliet (GT)

- JL stressed the importance of policy and procedure as levers in optimizing work in the Damage Control domain. He pointed out that navies are generally quite conservative organizations and are resistant to change, however, he can see that important changes can be made to damage control work.
- Mention was made of the report by Vallerand, Beevis, and Greenley (2001) that we already have in our possession; JL thought that we should take a look at what this report says on "Command Awareness Tools".
- Possible uses for insights on damage control – JSS, SCSC
- JL has made a visit to the Netherlands to see the systems on-board the Type 45 – it has an Integrated Platform Management System (**IPMS**) that centralizes reporting from all functions of the ship.
- JL stressed that in considering damage control it is very important to keep the command perspective in mind, and then to understand how command intent is filtered down through the various teams.
- In the opinion of JL and G we should try to get an interview with a CO or an XO when in Halifax to get their perspective on the damage control operations of a ship. (GT: Noted; we have to see how much time we have to do something like this; if we can do it, it could be a rich source of information for the Functional Purpose level of the AH.)
- A weakness of the current CPF DC system is that it is blunt – when smoke is detected, the shop goes into a smoke control environment in which everyone is wakened to be aware that there is danger. Better sensors could isolate damage to specific compartments and reduce the need for this approach.
- JL suggested that automation could keep the current context of the ship in mind – when steaming (not critical) DC systems could have a different automated response than in a battle situation. In JL's opinion, it would be important to have a veto over automation in the steaming situation, but that automation could be more autonomous as overall ship workload increased.
- JL's main message over the whole meeting was that any new technology for DC should provide better command situation awareness. The bridge needs the tools to better understand how the damage on the ship might affect their overall objectives, and then the ability to more easily prioritize the damage control effort. Especially needed was assistance to help identify the effect of damage on the ship's purposes to float, move, and fight.
- A decision tool is needed at the command level, as well as a way of communicating priorities down to the DCO.
- The bridge has the richest perspective on the overall functioning of the ship – Operations, Emergency Response Team, DC

- A good system would also help the bridge to better understand the current position and activities of the DC team.
- An expert system for monitoring the effects of damage could give engineers a better way of judging the effects of damage on the structural integrity of the ship.
- There is a broad possibility to help the information flow between the bridge, DC, and CSE.
- Information flow is one of the most important things in damage control; that's where things go wrong.
- Problem areas in DC: setting up of hoses, especially in the context of fire main breaks. CPF has a single fire main running down the length of the ship – not a ring system.
- **Action:** To find other problem areas, ask Sea Training where ships are failing in workups.
- The equipment that people wear is also an important constraint – ChemOx kits, etc. – they varying types of equipment change the ways that people fight fires. (GT: It is likely that we need to include this equipment as a part of the system.)
- **Action if pursuing:** Talk to Pat Deschenes about future equipment
- There is supposed to be a six-minute response time for a fire-fighting team; this is not always achieved, but not because the team isn't in place. Rather, it is because it can take longer than that to isolate power.
- Future directions for DC – the Chief of Defence Staff (**CDS**) is moving to a TCO model for ships, and is focussing less on acquisition and procurement costs separately.
- One important option for new ships would be to have breakers by compartment, on the outside. That way you can isolate power at the door, or you could even do it remotely. In all cases, it can also be important to offer manual overrides and battle short functionality.
- The challenge for automation is that a veto is generally needed; the automation might do good things, but operators want to be able to override it.
- Further, each HFX has its own idiosyncrasies; automation needs to be customizable to these particular details of each ship.
- DC Strategy for SCSC: Reduce TCO by looking to other projects around the world, with the proviso that navies are non-conformist and conservative.
- The SCSC is being considered to be a blank sheet from a design perspective; they are considering decision aids and automation.
- (At this point, one of the critical ship emergencies was mentioned – the loss of lube oil for main propulsion system.)
- Decision aid providers: CAE, Rolls Royce / Thyssen-Krupp, L3, Rockwell International / Sperry, SimSmart (who has a physics-based DC decision aid).
- Desire around the table was to move all decision aids up to the level of warfighting
- JL advised that we should try to see a ship in a state of action and a state of emergency. Talk to Dr. Hiltz about this.
- Normal problem on a CPF is a single hit, and a good scenario should include firefighting and repair.
- DC is also a medical environment – casualties need to be cleared and treated; we need to give careful consideration to how we add these to the DC AH.

January 24 – Visit with Chief Petty Officer Pretty

Attendees: Chief Petty Officer Kenneth Pretty (KP); Gerard Torenvliet

(Chief Pretty is the Project Director for Firefighting and Damage Control Systems. He is responsible for procurement and managing equipment projects.)

- Theme of KPs comments: automated systems are great, if they work. But they won't reduce manning because real bodies are needed to actually fight the fires.
- Much of our discussion was about the general organization of damage control efforts and equipment on the CPF.
- The manning pool is made up of people who don't have a purpose during action and emergency stations – mainly officers and bosuns.
- There are two emergency response teams (**ERT**s) each made up of 5 combat systems engineers (**CSE**s).
- The casualty clearing team (**CCT**) is responsible for moving casualties from areas of action to the sick bay and/or a secondary operating area.
- To understand the teams at work on a ship, try to get a copy of the Ship's Watch and Station Board. Look on the ship and/or get a copy from the Coxswain
- Section bases are only populated during emergency stations / action stations; 12-17 people in total
  - 1 in charge (IC)
  - 6 person fire-attack team[7] (nozzle man, backup man, hydrant man, attack team leader); the hydrant man monitors the hydrant and rigs the smoke curtains; the attack team leader guides and direct the effort and also uses a thermal imaging camera to find the fire; hydrant man also handles communications; there is also a backup team that goes along as well – they have a nozzle man and a backup man; it should be noted that the backup team does not have the equipment necessary to dispense AFFF unless AFFF is provided by the hydrant)
  - 2-3 person electrical repair party / casualty power team (could be up to five; one person must be a qualified electrician; they run casualty power cables to restore electricity)
  - 3-4 person flood repair / shoring party (hull technicians, or anyone – it takes five people to set up a shoring safely, and after a shoring is put in place, a sentry needs to monitor it)
- Under normal, non-action or emergency operations, HQ1 is staffed by one person who monitors the DC system and alarms; this is generally someone who is not standing some other watch. HQ1 also has a roundsman who makes the rounds of the ship to do whatever is required when the officer of the watch (OOW) makes changes to the damage control status of the ship (e.g., helo launches); typically this involves closing hatches.
- HQ1 is in the Machinery Control Room; under normal operations the DC person on duty is with the people from the Engineering Watch (Chief of the Watch, MCC watch keeper, Electrician); this team also has two roundsmen to go around the ship doing engineering maintenance tasks as necessary.
- The Aft and Forward section bases each have an electrical switchboard and an electrician.
- Section base also has two roundsmen who go around being the remote eyes and ears of the section base IC.
- Other section base staff: Plotter/Recorder (also does comms); In Charge (Petty Officer or Chief Engineer); Hull tech (also second IC), assistant engineer.

[7] Anyone can be in an attack team; all are so trained.

- Once a fire has been put out, sentries monitor it until it has cooled. Also, any repair, shoring etc requires a sentry to confirm that all is well.
- Section base 3 – closes up the hangar – made up of 23 aircrew whose primary purpose is to support the helicopter
- Manning pool has 9-20 people, always ready to fight a fire
- Fires spread because bulkheads get hot and things that touch the bulkhead ignite; or they spread because people leave doors open.
- References: Check US NAVSEA website; it has lessons learned from the Stark and Cole.
- (KP will be posted to civil service in the month, but will still be available to help us should the need arise.)

January 24 – Visit with LCdr Grychowski

Attendees: LCdr Bruce Grychowski (BG); Gerard Torenvliet

- There are two classifications of scenarios for damage control – peacetime operations (damage by accidents; effects are localized unless things get out of hand) and battle damage effects.
- Marine Systems runs the DC organization; they can do equipment isolation and repair but they are not good at it.
- Combat Systems is for equipment isolation and repair
- Challenge with damage control and manning – you need to change people out. Worst case is a fire in and/or around fuel and explosives causing secondary damage that cannot be contained for many hours. The same team cannot keep on fighting this fire; instead you have to get people out and fresh teams in.
- With flooding as a result of collision or other damage, the flooding is isolated by bulkhead and pumped out. Creeping damage comes by surging.
- When in Sea State 6 there are environmentally induced injuries to worry about as well; people are going to be hitting the walls and falling.
- Smoke control is achieved by manipulating the ventilation system. This can be a good thing but it also feeds the fire.
- Fires in ships become dangerous very quickly. BG told a story of a fire on the Assiniboine in 1982 – a fire started in a bag of rags and linseed oil – heated hot very fast, lots of smoke, and aluminium melted. It almost spread to a welding kit… and all of this happened in under 10 minutes.
- There is a necessity to monitor fires after the fact, and even hose them down. Fitted systems aren't very good for this, but a hose works really well. (Note that you prevent fires from spreading by making a boundary and continuing to ensure that the bulkheads at the boundary don't get too hot, if possible. You also need to move all stuff away from the walls.)
- Purposes of DC – survival of ship and protection of life
- Battle damage by explosives involves structural damage. The UK Sheffield was hit by a missile and almost as much damage was caused by the leftover fuel as by the missile itself. Fitted fire suppression systems were degraded or destroyed.
- Missiles cause flooding, fire, structural damage, power problems, and injuries.
- If a missile hits the boat, the switchboard will get jarred which may cause breakers to break and no longer work.

- In a DC situation, it is a command decision to isolate systems or to keep them running and risk them breaking.
- ERT: Responds to hazmat spills; must keep the combat system operational; can perform rapid response to fire and flood.
- CSEs work on problems internal to ship’s equipment, and they also do rounds to monitor the status of combat systems.
- After 20 minutes wearing fire gear you need a rest, so you continually cycle through batches of people; scenarios need to consider this as well as people being out of commission due to casualties.
- Surveying the ship (rounds) wastes manpower.
- Documents we should get: ERT Pack (about the combat systems on the CPF)
- FTA – Mr. Jim Bureaux has drawings of the CS in detail. L.T. Taylor (MSE) has the MS in detail.
- Don’t forget the upper deck – the mast structure, fittings, weapons, and antennae. In a high sea state it is difficult to access these, and the presence or absence of an antenna can determine what gear should be fixed or not.

Actions

- Request compartment risk profile (*complete; LCdr Heimpel is trying to get a copy of this from one of the ships*)
- Get information on damage control organization (*complete; I have a copy of the Ship Standing Orders*)
- Try to get an interview with CO or XO of a ship (*will see how this fits in the schedule next week*)
- If we need information on firefighting equipment, meet with Pat Deschenes.
- Get a copy of the Ship’s Watch and Station Board
- Check US NAVSEA website for lessons learned from the USS Stark and USS Cole
- Get an ERT Pack

ANNEX D
BIBLIOGRAPHY OF CPF DOCUMENTATION

ANNEX D: BIBLIOGRAPHY OF CPF DOCUMENTATION

The following is a list of the CPF documentation that was consulted during the conduct of the work described in this volume.

1. Canadian Department of National Defence (2003a). Canadian Navy Damage Control Information Book for Halifax Class Ships (Manual No. C-23-HFX-000/MS-002).

2. Canadian Department of National Defence (2003b). Naval Engineering Manual, Volume 1 (Manual No. C-03-005-033/AA-000).

3. Canadian Department of National Defence (1994). Damage Control System Model #SYS-00501-00: Operation, Installation, and Maintenance (Books 1 through 5).

4. Canadian Department of National Defence (2004). Shipboard Damage Control (Volumes 1 and 2).

5. Canadian Department of National Defence (undated). Maritime Command: Ship's Standing Orders, version AL6.

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Modélisation fonctionnelle, élaboration de scénarios et analyse des options à l'appui de l'optimisation de l'armement en équipage aux fins du contrôle des avaries − Phase 1 : Modélisation fonctionnelle

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(U) The Canadian Navy hopes to achieve significant lifetime cost reductions by implementing optimized crew levels across its next−generation fleet. Defence Research and Development Canada (DRDC) has recognized that optimized crewing can only be achieved through a thorough Human−Systems Integration (HSI) effort, and that this effort will require systems modelling techniques to help the Navy predict the effectiveness of technologies and work strategies that aim to reduce operator workload and improve mission success. This report describes the first phase of a project undertaken to provide DRDC with such a technique, and details the development of an Abstraction Hierarchy (AH) functional model of the domain of damage control. Two subsequent phases of analysis are planned: to develop damage control scenarios, and to identify emerging damage control technologies and the reduced crew levels required to support them. These will be used as inputs for a follow−on project to develop a simulation of human and automated work in the damage control domain. The AH model documented in this report is a strong basis for the subsequent phases of this project, and the follow−on simulation development effort.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) damage control, crewing, automation, modelling, work domain analysis

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